Final Report Volume III
Supporting Data
D180-27487-3

Advanced Platform Systems Technology Study

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April 1983

BOEING

ADVANCED PLATFORM SYSTEMS TECHNOLOGY STUDY

Final Report

VOLUME III

SUPPORTING DATA

D180-27487-3

Conducted for NASA Marshall Space Flight Center

Under Contract Number NAS8-34893

April 1983

Boeing Aerospace Company

Spectra Research Systems

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LIST OF ACRONYMS AND ABBREVIATIONS

ACS	Attitude Control System
AGC	Automatic Gain Control
APD	Avalanche Photo Diode
ARC	Ames Research Center
ASE	Airborne Support Equipment
ATP	Authority to Proceed
BIT	Built-in Test
BTU	British Thermal Units
BW	Bandwidth
CCTV	Closed Circuit TV
CDR	Critical Design Review
CELSS	Controlled Ecological Life Supply System
CG	Center of Gravity
CMG	Control Moment Gyro
CMOS	Complimentary Metal Oxide Semiconductor
cm/sec	Centimeters Per Second
CMOS/SOS	CMOS/Silicone on Sapphire
CRC	Cyclical Redundancy Check
CRT	Cathode Ray Tube
dB	Decibels
DISCO	Distributed Star Coupled
DOD	Department of Defense
EC/LSS	Environmental Control-Life Support System
EMI	Electro-Magnetic Interference
EMU	Extra-Vehicular Mobility Unit
ETVP	Engineering Test Verification Platform
EVA	Extra Vehicular Activity
FDS	Frequency Division Multiplexing
F/O	Fiber Optic
ft	Feet
FY	Fiscal Year
GBPS	Giga Bits Per Second
GEO	Geostationary Orbit
GSFC	Goddard Space Flight Center
HM	Habitat Module
H/O	Hydrogen-Oxygen
hr	Hour
Hz	Hertz
IAC	Integrated Analysis Capability
IAF	International Aeronautical Federation
IBM	International Business Machines
IC	Integrated Circuits
IEEE	Institute of Electrical, Electronics Engineers
ILD	Injection Laser Diode

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

IR	Infrared
ISO/OSI	International Standards Organization/Open System-Interconnect
IVA	Intervehicular Activity
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
K	Thousand
KBPS	Kilo Bits Per Second
KG	Kilo Group
km	Kilo Meter
kW	Kilowatts
kWhr	Kilowatt Hours
LAN	Local Area Network
lb	Pound
LED	Light Emitting Diode
LEO	Low Earth Orbit
LISP	List Processor
LM	Logistics Module
LOX	Liquid Oxygen
LRU	Line Replaceable Units
LSI	Large Scale Integration
LSS	Life Support System
LV/LH	Local Vertical/Local Horizontal
M	Million
MBPS	Millions of Bits Per Second
MHz	Mega Hertz
MIPS	Millions of Iterations Per Second
MMS	Multimission Modular Spacecraft
MPS	Meters Per Second
MSFC	Marshall Space Flight Center
MSI	Medium Scale Integration
MTBF	Mean Time Before Failure
NASA	National Aeronautics and Space Administration
NIM	Network Interface Module
nm	Nautical Miles
NMS	Newton-Meter-Seconds
NOS	Network Operating System
OPERA	Orbital Payload Environmental Radiation Analyzer
OTV	Orbital Transfer Vehicle
PCS	Plastic Clad Silica
PIN	Positive Intrinsic Negative
psia	Pounds Per Square Inch Absolute
RCA	Radio Corporation of America
RCS	Reaction Control System

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

RFI	Radio Frequency Interference
RPM	Revolutions Per Second
SAR	Synthetic Aperture Radar
SADMP	Science and Applications Manual Space Platform
SASP	Science and Applications Space Platform
sec	Seconds
SOC	Space Operations Center
SIF	Systems Integration Facility
SRS	Spectra Research Systems
SSI	Small Scale Integration
STS	Space Transportation System
TCS	Thermal Control System
TDRSS	Tracking Data Relay Satellite System
TOC	Total Organic Carbon
TV	Television
ULSI	Ultra-Large Scale Integration
VAX	Virtual Address Extension
VHSIC	Very High Speed Integration Circuit
VLSI	Very Large Scale Integration
WDM	Wavelength Division Multiplexing
WQM	Water Quality Monitor

FOREWORD

The Advanced Platform Systems Technology Study (Contract NAS8-34893) was initiated in July 1982 and completed in April 1983. The study was conducted for the National Aeronautics and Space Administration, Marshall Space Flight Center, by the Boeing Aerospace Company with Spectra Research Systems as a subcontractor. The study final report is documented in four volumes.

D180-27487-1	Vol. I	Executive Summary
D180-27487-2	Vol. II	Trade Study and Technology Selection Technical Report
D180-27487-3	Vol. III	Support Data
D180-27487-4	Vol. IV	Technology Advancement Program Plan

Mr. Robert F. Nixon was the Contracting Officer's Representative and Study Technical Manager for the Marshall Space Flight Center. Dr. Richard L. Olson was the Boeing study manager and Mr. Rodney Bradford managed the Spectra Research Systems effort.

1.0 INTRODUCTION

This is volume III of the final report on the Advanced Platform Systems Technology Study conducted for the Marshall Space Flight Center by the Boeing Aerospace Company and Spectra Research Systems. The overall study objective was to identify, prioritize, and justify the advancement of high leverage technologies for application on the early space station. The objective was fulfilled through a systematic approach to trade study identification and selection, trade study analysis, and selection of technology advancement items. This volume presents the formatted data sheets that were filled out as part of the study procedure.

The overall study effort proceeded from the identification of 106 technology topics to the selection of 5 for detail trade studies. The technical issues and options were evaluated through the trade process. Finally, individual consideration was given to costs and benefits for the technologies identified for advancement. Eight priority technology items were identified for advancement and are reported in volume II together with the rationale and justification for their selection. A plan for advancing each of the eight technology items is presented in volume IV of this report. This volume contains selected supporting data generated during the trade selection and trade study process. Volume I summarizes the overall study approach and results.

The study was divided into three primary tasks which include task 1—trade studies, task 2—trade study comparison and technology selection, and task 3—technology definition. Task 1 general objectives were to identify candidate technology trade areas, determine which areas have the highest potential payoff, define specific trades within the high payoff areas, and perform the trade studies. In order to satisfy these objectives, a structured, organized approach was employed. Candidate technology areas and specific trades were screened using consistent selection criteria and considering possible interrelationships. Figure 1.0-1 displays the overall screening process.

The selection flow is shown in figure 1.0-2. The study started with space platform requirements, proceeded through trade study and cost benefits analysis, to technology advancement planning. The structured approach used in the study took advantage of a number of forms developed to ensure that a consistent approach was employed by each of the diverse specialists that participated in the study. These forms were an intrinsic part of the study protocol.

PT 0036

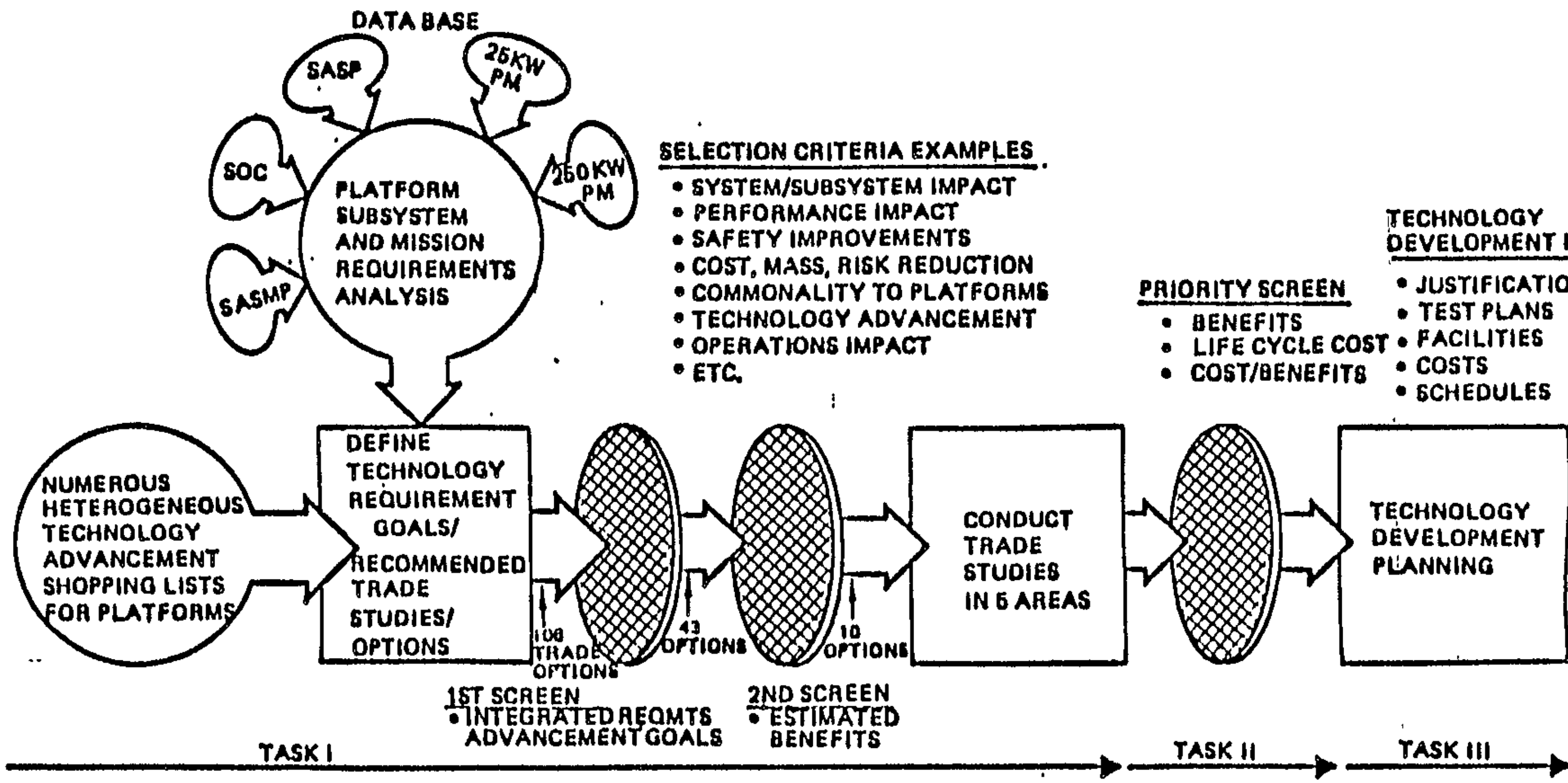

Figure 1.0-1. Study Concept Features Multiple Evaluation and Selection Screening to Identify Most Promising Platform Technologies

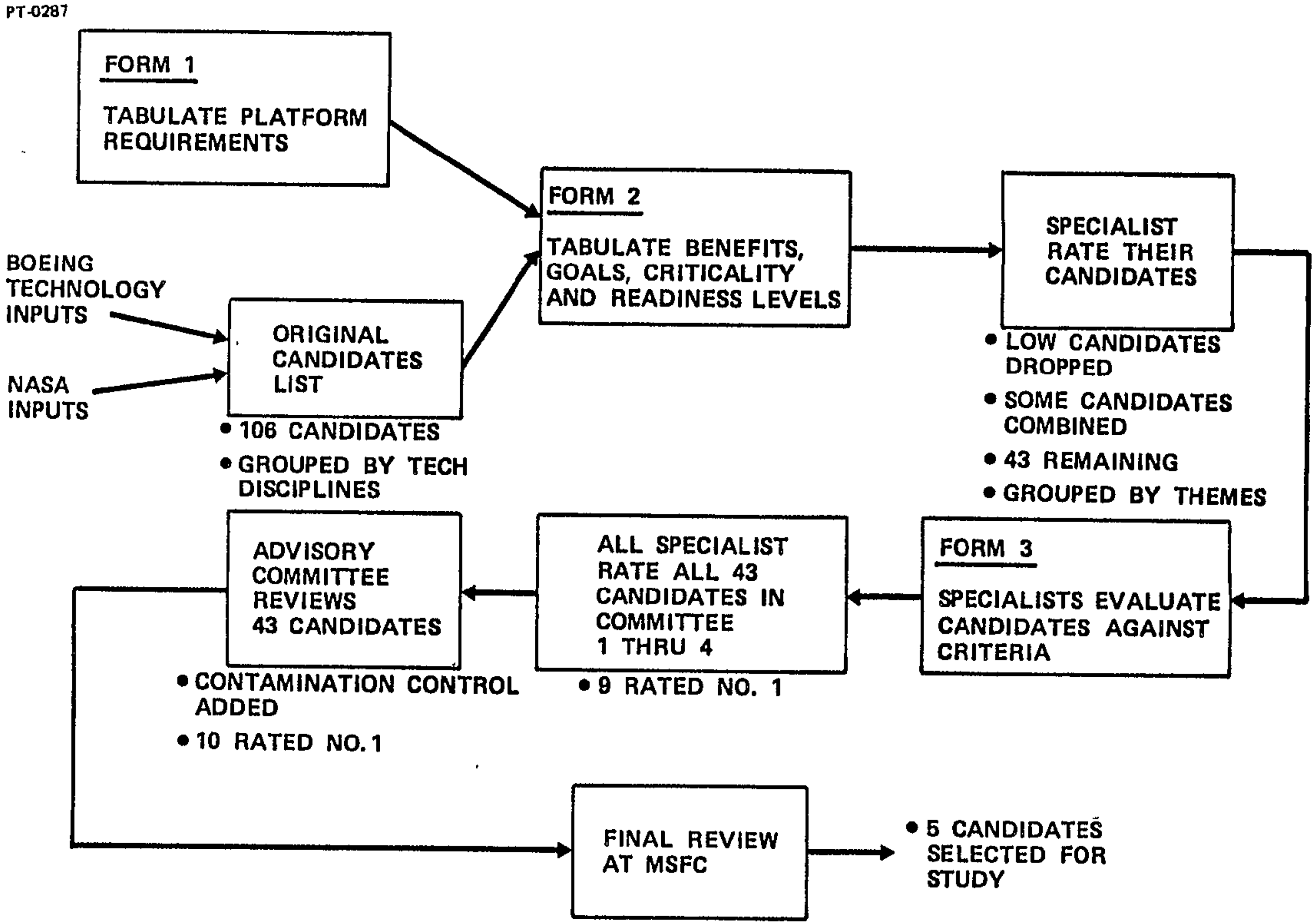

Figure 1.0-2. Candidate Selection Flow

Example forms are shown in figures 1.0-3, -4, and -5. Form 1 was used to record and organize requirements. The completed copies of Form 1 are presented in section 2.0 of this volume of the Final Report. Form 2 was used to record trade study advancement goals and benefits and list technology options. Section 3.0 of this volume contains the filled in Form 2 copies. Form 3 contained a listing of the initial selection criteria. Section 4.0 presents the filled in copies of Form 3.

The task 2 objective was to evaluate the results of the trade studies performed in task 1, prioritize and select technologies with respect to comparative cost and benefit potential in the context of overall system compatibility. The task was accomplished in four primary steps in which advancement costs, schedules, comparative benefits and platform life-cycles costs were used to rank, order, and select the most promising technologies requiring advancement. Section 5.0 of this volume contains the completed copies of Form 3A which summarize the results of the trade studies in four technology areas (data management architecture, data management-data bus, long lifetime thermal management, and integration of automated housekeeping functions).

The primary objectives of task 3 were to provide the justification for technology advancement based on the detailed trade studies and benefit analysis and to prepare the test plans for each technology item identified. The advancement plan includes rationale, benefits, resources costs and schedules keyed to a platform program development schedule. Volume IV of this report presents the results of task 3.

REQM'T CODE NO.	TECHNOLOGY DISCIPLINE / REQUIREMENT ** ** = MISSION ENABLING REQM'T	MANNED PLATFORMS: EARLY LEO SASMP	MANNED PLATFORMS: EARLY LEO SOC	MANNED PLATFORMS: ADVANCED LEO SASMP	MANNED PLATFORMS: ADVANCED LEO SOC	MANNED PLATFORMS: GEO SOC	UNMANNED PLATFORMS: EARLY SASP	UNMANNED PLATFORMS: INTERMEDIATE SASP	UNMANNED PLATFORMS: ADVANCED SASP	UNMANNED PLATFORMS: 250 KW PWR MOD	UNMANNED PLATFORMS: GEO COM PLAT
	RADIATOR SYSTEM PM = POWER MODULE SM = SERVICE MODULE HM = HABITAT MODULE	PM • Deployable/ Constructable • 19.2 kW_T rejection • Non-toxic loop to HM • ------- • -------	SM • Deployable/ Constructable • 18.2 kW_T rejection • ------- HM • Deployable • Integral w/ Meteoroid Shield • 13.2 kW_T max./HM • Non-toxic interior loop (dual loop) •	PM • Deployable/ Constructable • 32.4 kW_T Rejection • Non-Toxic Loop to HM • -------	SM • Deployable/ Constructable • ------- HM • Deployable • Integral w/ Meteoroid Shield • 13.2 kW_T max./HM • Non-toxic Interior Loop (Dual Loop)	SM • Deployable/ Constructable • ------- • ------- HM • Deployable • Integral w/ Shield • Non-toxic Interior Loop (Dual Loop) •	• Deployable/ Constructable • ------- • ------- • -------	• Deployable/ Constructable • 25 kW_T Nom. • -------	• Deployable/ Constructable • 25 kW_T/ Payload • -------	Not Defined	• Deployable/ Constructable • 0.2 kW_T per module (Comm Sys) • ------- • ------- 2 Constellation 6 Platform/ Constell. Only Others Not Defined

Figure 1.0-3. Form No. 1 – Platform Requirements Compilation Form

Technology Discipline / Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int. LEO	Unmanned Platforms: Adv LEO	Unmanned Platforms: GEO	Technology Criticality Category	Specific Trades	Options	Current Technology Readiness Level	Technology Context
DEVELOP THERMAL MANAGEMENT SYSTEM CAPABLE OF ACCOMMODATING INTER-CHANGEABLE PAYLOADS/VARYING THERMAL LOADS	• More Efficient Energy Use • Higher Reliability • Reduced Hardware Requirement • Reduced Weight • ------- • -------	•	•	•	•	•	•	•	Tech Adv. Req'd	Decentralized vs Centralized Thermal Management Systems Centralized System • Evaluate Competing Thermal Bus Concepts • Identify PM/Bus Heat Exchanger Link • Evaluate Applicable Radiator Systems • Evaluate Applicable P/L Interfaces	• Single Centralized • Multiple Centralized • Decentralized (P/L) • Single Phase Pumped Loop • 2 Phase Pumped Loop • High Capacity Heat Pipe • ------- • Deployable • Constructable • Forced Flow • Heat Pipe • Fixed • Moveable	----- ----- 6 6 3–5 3 ----- ----- 4–6 ----- ----- ----- -----	

Figure 1.0-4. Form No. 2 – Technology Advancement Identification Form

PT-0031

TECHNOLOGY DISCIPLINE	THERMAL CONTROL
TECHNOLOGY ADVANCEMENT GOAL	DEVELOP THERMAL MANAGEMENT SYSTEM CAPABLE OF ACCOMMODATING INTERCHANGEABLE PAYLOADS/VARYING THERMAL LOADS
SPECIFIC TRADE	DECENTRALIZED VS CENTRALIZED THERMAL MANAGEMENT SYSTEM

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	REDUCED ENERGY REQMTS (INSTR. HEATING & ACTIVE ELEMENT CONSUMPTION)
• SUBSYSTEM IMPACTS	> 50% REDUCTION IN S/S HARDWARE
• PERFORMANCE IMPROVEMENTS	68–92% INCREASE IN P/L HEAT REJECTION CAPABILITY
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	ALL ACTIVE ELEMENTS REPLACED BY PASSIVE COMPONENTS
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

Figure 1.0-5. Form 3–Specific Trade Benefits Estimate

2.0 REQUIREMENTS SURVEY (FORM I)

This section presents the data sheets containing the results of surveying the following platform source data to identify requirements:

NASA Contractor Report No. 160944 - January 1982
Requirements for a Space Operations Center

Boeing Document D180-26495 - NAS9-16151 - July 1981
Space Operations Center Final Report

NASA PM-001 - September 1979
25K Power system Reference Concept (Prelim.)

MDC G9246 - Technical Report - NAS8-33592 - October 1980
Conceptual Design Study, Science and Applications Space Platform (SASP)

NASA Report - MSFC - October 1981
A Conceptual Design and Analysis Study Program Development, Science and Applications Manned Space Platform (SAMSP)

The sheets are provided for the following technology disciplines

Thermal Control
Structures Mechanisms and Materials
Crew Systems
Flight Operations
Ground Operations
Data Management
Communications and Tracking
Electrical Power System
Propulsion System
Guidance and Navigation Technology
Attitude Control

Identified requirements or subsystem descriptions are listed for each of these according to early and advanced manned platforms (SASMP and SOC), according to an early intermediate and advanced unmanned SASP, and for the unmanned 25K power module platform.

Reqmt Code No.	Technology Discipline: FORM 1	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
	Requirement ** **—Mission Enabling Reqmt	SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	Controller	. Centralized controller . Distributed sensors Distributed flow control valves	. Centralized control of main thermal bus . Distributed control of intermediate loops	. Centralized controller . Distributed sensors . Distributed flow control valves	. Centralized control of main thermal bus . Distributed control of intermediate loops	. Centralized control of main thermal bus . Distributed control of intermediate loops	. Centralized controller . Distributed sensors . Distributed flow control valves	. Centralized controller . Distributed sensors . Distributed flow control valves	Centralized controller . Distributed sensors . Distributed flow control valves	
	Fault Detection & Isolation	. Redundancy pumps valves . Status sensors	. Redundancy . Status sensors	. Redundancy pumps valves . Status sensors	. Redundancy . Status sensors	. Redundancy . Status sensors	. Redundancy pumps valves . Status sensors	. Redundancy pumps valves . Status sensors	. Redundancy pumps valves . Status sensors	
	Rotating Thermal Joint	. Flex lines	. Contact joint . 360° rotation	. Flex lines	. Contact joint . 360° rotation	. Contact joint 360° rotation	. Flex lines . +/- 90° rotation	. Flex lines . +/- 180° rotation	. Flex lines . +/- 180° rotation	
	Cabin Air Heat Exchanger	. Req'd	. Req'd	. Req'd	. Req'd	. Req'd	N/A	N/A	N/A	N/A
	Contact Heat Exchangers	N/A	. Enhanced performance joint	N/A	. Enhanced performance joint	. Enhanced performance joint	N/A	N/A	N/A	
	Energy Transport Lines	. Liquid . Supply . Return . Meteoroid protection . Valves . Tees . Parallel loops	. 2-phase . Supply . Return . Meteoroid protection on main bus	. Liquid . Supply . Return . Meteoroid protection . Valves . Tees . Parallel loops	. 2-phase . Supply . Return . Meteoroid protection on main bus	. 2-phase . Supply . Return . Meteoroid protection on main bus	. Liquid . Supply . Return . Meteoroid protection . Valves . Tees . Parallel loops	. Liquid . Supply . Return . Meteoroid protection . Valves . Tees . Parallel loops	. Liquid . Supply . Return . Meteoroid protection . Valves . Tees . Parallel Loops	
	Fluid Line Disconnects	. One pair to HM . Pairs to payload berths	N/A	. One pair to each HM Pairs to each payload berths	N/A	N/A	. 3 pairs to 3 berths	. 5 pairs to 3 berths	. X pairs to berths	Not defined

Requirements Survey for Thermal Control

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Reqmt Code No.	Technology Discipline: FORM 1 Requirement ** **—Mission Enabling Reqmt	Manned Platforms Early LEO SASMP	 SOC	 Advanced LEO SASMP	 SOC	 GEO SOC	Unmanned Platforms Early SASP	 Intermediate SASP	 Advanced SASP	 250 kw Fwd Mod
	Radiator PS = Power System SM = Service Module HM = Habitat Module	PS Deployable . 19.2 KW rejection . meteoroid protection	SM . Constructible . 16.2 KW rejection HM . Deployable . meteoroid protection . 13.2 KW max per module . Nontoxic working fluid within pressure shell	PM . Deployable/constructible . 32.4 KW rejection . Meteoroid protection	SM . Constructible .150 KW max HM . Deployable . Meteoroid protection . 13.2 KW max per module . Nontoxic working fluid within pressure shell	SM . Constructible . 250 KW max	PS . Deployable . 25 KW rejection . Single phase . Meteoroid protection Pallet . Fixed . 3 KW rejection Trail Arm . Fixed	PS . Deployable 25 KW rejection . Single phase . Meteoroid protection Pallet . Fixed . 3 KW rejection Trail Arm . Fixed	PS . Deployable . 25 KW rejection . Single phase . Meteoroid protection Pallet . Fixed . 3 KW rejection Trail Arm . Fixed	
	Thermal Storage	Not defined (Probably required)	. Req'd part of thermal transport	. Not defined (Probably required)	. Req'd part of thermal transport loop	. Req'd part of thermal transport loop	. Not defined (Probably required)	. Not defined (Probably required)	. Not defined (Probably required)	
	Cold Plates	. Integral with PS equipment mounting	. Req'd	. Integral with PS equipment mounting	. Req'd	. Req'd	. Integral with PS equipment mounting . Quick release equipmnt hold downs	. Integral with PS equipment mounting . Quick release equipment hold downs	. Integral with PS equipment mounting . Quick release equipment hold downs	
	Pumps	. Continuous operation	. Intermittent operation	. Continuous operation	. Intermittent operation	. Intermittent operation	. Continuous operation except during dormancy	. Continuous operation except during dormancy	. Continuous operation except during dormancy	

Requirements Survey for Thermal Control (Cont'd)

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Reqmt Code No	Technology Discipline: STRUCTURES, MECHANISMS & MATERIALS — FORM 1 Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASMP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Fwd Mod
	Mechanism Design									
	. Deployment Mechanisms	. Solar array . Experiment appendages . Antenna . Radiators	. Solar array . Antenna . Radiator	. S/A . Experiment appendages . Antenna . Radiator	. S/A . Antenna . Radiator	. S/A . Antenna . Radiator	. S/A . Exp append. . Antenna . Radiator	. S/A . Exp. append. . Radiator	. S/A . Exp. append. Radiator	S/A . Exp append . Radiator
	. Docking/Berthing Mechanisms	X	X	X	X	X	X	X	X	X
	. Articulating/Rotary Joints . Electro-Mechanical Actuators	. Solar arr . Experiment/docking interfaces . Deployment actuators . Rotary joints	. Solar arr . Deployment actuators . Rotary joints	. Solar arr . Exp/docking interfaces . Deployment actuators . Rotary joints	. Solar arr . Deployment actuators . Rotary joints	. Solar arr . Deployment actuators . Rotary joints	. Solar arr . Exp/docking interfaces . Deployment actuators . Rotary joints	. Solar arr . Exp/docking interfaces . Deployment actuators . Rotary joints	. Solar arr . Exp/docking interfaces Deployment actuators . Rotary joints	. Solar Arr . Exp/docking interface . Deployment actuators . Rotary joints
	. Tracks and Mobility Systems	N/A	. Fixed manipulator	. Fixed manipulator	. Tracked manipulator	. Tracked manipulator	N/A	N/A	N/A	N/A
	Materials									
*	. Composites (Organic, Metal Matrix)	X	X	X	X	X	X	X	X	X
*	. Composites Lifetime & Properties Pred.	X	X	X	X	X	X	X	X	X
	. Paints and Coatings For Interiors	X	X	X	X	X	N/A	N/A	N/A	N/A
	. Definition of Contamination Sources	X	X	X	X	X	X	X	X	X
	Testing on Orbit Required for New Concept -									
	Techniques for cost effective testing -									

Requirements Survey for Structures Mechanisms and Materials

Reqmt Code No.	Technology Discipline: FORM 1 — STRUCTURES, MECHANISMS & MATERIALS. Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO SAMSP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SAMSP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Pwr Mod
	STRUCTURAL CONCEPTS									
	. System Considerations	X	X	X	X	X	X	X	X	X
	. Evolutionary Configuration	X	X	X	X	X	X	X	X	
	. Fail Safe Structures	X	X	X	X	X	X	X	X	X
	. Packaging	X	X	X	X	X	X	X	X	X
	STRUCTURAL PERFORMANCE									
	System Identification	X	X	X	X	X	X	X	X	X
	. Dynamics Prediction Methods	X	X	X	X	X	X	X	X	X
	. Structural Damping	X	X	X	X	X	X	X	X	X
	. Structural/Thermal Analysis	X	X	X	X	X	X	X	X	X
	. Dynamics/Control	X	X	X	X	X	X	X	X	X
	. Loads/Environments	X	X	X	X	X	X	X	X	X

Requirements Survey for Structures Mechanisms and Materials (Cont'd)

Reqmt Code No.	Technology Discipline FORM 1 — Requirement *****—Mission Enabling Reqmt**	Manned Platforms — Early LEO SASMP	Early LEO SOC	Advanced LEO SASMP	Advanced LEO SOC	GEO SOC	Early SASP	Unmanned Platforms — Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	EVA Support									
	The capability shall be provided for voice communication with deployed EVA crewmen out to TBD meters	X	X	X	X	X				
	Translation means will include handrails/handholds/slidewires and other mobility and stability aids such as manipulators and the manned maneuvering unit (MMU).	X	X	X	X	X	X	X	X	
	Handholds, handrails, and restraint attach points shall be provided along all EVA routes and at each EVA hatch. Attachment provisions for portable handholds and restraint systems shall be provided at remote work sites.	X	X	X	X	X	X	X	X	
	Locomotion, restraint devices, and portable EVA work stations will be provided.	X	X	X	X	X				
	Provide for simultaneous EVA's of TBD crewmen during initial operations and for a minimum of TBD crewmen during subsequent growth phases.	X	X	X	X	X				
	A minimum of two MMU support stations shall be provided during growth phases. The MMU's shall be protected from the hazards of space and vacuum exposure during stowage and servicing.	X	X	X	X					
	Management of consumables for the EVA equipment shall be provided.	X	X	X	X	X				
	EVA audio and visual displays for EVA support shall be provided along with uplink and downlink capabilities	X	X	X	X	X				
	The maximum EVA duration will be 8 hours per crewman per 24-hour day. In addition to the 8-hour EVA period, there will be a 30-minute period for each of the pre- and post-EVA operations (suit donning/doffing and airlock egress/ingress).	X	X	X	X	TBD				
	Provide the capability to service the regenerable extravehicular mobility unit (EMU) including the processing of the crew's metabolic carbon dioxide and waste water and the refreezing of the nonexpendable heat sink. Servicing capabilities shall be based on a minimum of 24 8-hour EVA's per week.	X	X	X	X	TBD				

Requirements Survey for Crew Systems

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Reqmt Code No.	Technology Discipline — FORM 1 Requirement ** **—Mission Enabling Reqmt	Manned Platforms — Early LEO — SASSP	Manned Platforms — Early LEO — SOC	Manned Platforms — Advanced LEO — SASSP	Manned Platforms — Advanced LEO — SOC	Manned Platforms — GEO — SOC	Unmanned Platforms — Early SASP	Unmanned Platforms — Intermediate SASP	Unmanned Platforms — Advanced SASP	Unmanned Platforms — 280 km Fwd Mnd
	EVA Support - Con't									
	"Prebreathe" by an EVA crewman shall not be required prior to an EVA. EVA suits will be supplied with oxygen from the Space Station.	X	X	X	X	X				
	Provide the capability to support multiple EVA's during any given time frame. To reduce procedural or safety concerns, provide multiple EVA airlocks. EVA shall be conducted using the "buddy" system.	X	X	X	X	X				
	Provide a variable controlled rate of depressurization and pressurization of the EVA airlocks. The nominal rates are to be +/-0.1 psi/sec. The emergency rapid depressurization and pressurization shall not exceed +/-1 0 psi/sec. Control of depressurization and pressurization shall be possible from both inside and outside the Space Station as well as from within the airlock. Life support umbilical connectors shall be available both inside and outside the Space Station's pressurized compartment to allow umbilical EVA operations.	X	X	X	X	X				
	Provisions for EVA preparation, EVA equipment stowage, recharge, checkout, maintenance (including drying), and post-EVA activities shall be made in the airlock and/or in an adjacent pressurized compartment. The maintenance area must accommodate stowage of EMU spare parts and tools. Provisions to verify the acceptability of an EMU for EVA, following its repair or resizing, must be provided in the work area.	X	X	X	X	X				
	Details regarding visual contact with an EVA astronaut are TBD.	X	X	X	X	X				
	. The EVA airlock shall provide adequate volume for stowage of EVA equipment and for the suited crewman to function and maneuver. Available volume should provide adequate space for the observer during the donning and doffing of EVA suits.	X	X	X	X	X				
	. It is desirable that the EVA airlock be located as an appendage to the living/working areas.	X	X	X	X	X				
	. Battle lanterns shall be provided for the EVA lighting. They shall be mounted on rails and equipped with swivel or gimbal mounts.	X	X	X	X	X				
	. EVA shall be considered a normal mode for repair.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Report Code No.	Technology Discipline: [illegible] — Requirements — Mission Enabling Request	Manned Platforms — Early LEO — SASP	Manned Platforms — Early LEO — SOC	Manned Platforms — Advanced LEO — SASP	Manned Platforms — Advanced LEO — SOC	Manned Platforms — GEO — SOC	Unmanned Platforms — Early SASP	Unmanned Platforms — Intermediate SASP	Unmanned Platforms — Advanced SASP	Unmanned Platforms — 250 kw Pwr. Mod.
	Food and drink - The station will provide a galley system to provide the requisite food and drink for the crew.									
	a. Food: Varied and complete meals will be furnished for the crews. In addition, snack items will be provided. The food shall consist of items that are hot, cold, and room temperature. The meals shall be nutritionally balanced and palatable to the crews. Condiments shall be provided for variety. Bulk storage and preparation shall be considered.	X	X	X	X	X				
	b. Drink: Varied types of drinks (hot, cold and room temperature) will be provided	X	X	X	X	X				
	c. Galley: The galley will provide for meal preparation, both heating and cooling and serving. Stowage of all utensils, food, condiments, and accouterments necessary for the food preparation and eating shall be included. The galley shall also provide for the cleanup and trash management of the food system.	X	X	X	X	X				
	d. Dining: Sufficient volume will be allotted to seat and feed the entire crew at each meal. The crews will be able to dine together as a group. This volume can be utilized as a wardroom/lounge between meals.	X	X	X	X	X				
	Lighting: The station will provide adequate lighting levels and sunlight control in each habitable portion of the station. The lighting system will be such that adequate light is available for all envisioned tasks as well as for living within the station. Particular care will be maintained to prevent shadowing, high contrast, glare, and light shining directly into the eyes of a crewmember during the performance of envisioned tasks as well as during general movement about the station. The light levels shall be in accordance with specifications TBD.	X	X	X	X	X				
	. Each activity shall be provided with lighting controls for area lights. These controls shall be conveniently located to provide lighting adjustment as external orbital lighting conditions change.	X	X	X	X	X				
	. Night light route locators shall be provided in areas normally darkened for sleep or work.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

Request Code No.	Technology Discipline: FORM 1 — Requirements — Mission Enabling Request	Manned Platforms: Early LEO SASSP	Early LEO SOC	Advanced LEO SASSP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	250 kw Free Flyer
	. Lighting of personal hygiene areas shall be adequate for reading and cleaning.	X	X	X	X	X				
	Acoustics: The station will provide sufficient sound control to reduce all station-produced noises to the minimum level reasonably achievable. The crews must be able to converse without shouting and must be able to hear the various caution and warning systems and communication systems without specialized hearing aids or locations. The use of "white noise" to cover background noise and disturbances is not permitted as a sound control device. The noise levels by exposure duration, frequency content, and activity in the various station locations are TBD. The noise level in the sleeping quarters requires special consideration.									
	Environmental Control and Life Support Systems									
	The critical functions of the Space Station environmental control and life support (ECLS) system include (1) atmosphere revitalization, (2) atmospheric pressure and composition control, (3) cabin temperature and humidity control, (4) water reclamation, (5) personal hygiene and waste management, and (6) habitability provisions. The habitat module ECLS shall embody regenerative concepts to an optimal degree to minimize the resupply expendables and shall have the necessary flexibility and expansion capability to accommodate the phased evolutionary growth of the Space Station. For example, during the initial Space Station buildup, early manned operations may require the use of a Shuttle-derived open-cycle ECLS until the habitat module is in operation.	X	X	X	X	X				
	General Requirements									
	The following general requirements apply to both open-cycle and regenerative ECLS subsystems.	X	X	X	X	X				
	a. The ECLS subsystem shall control the Space Station pressurized environment to the values indicated in Table 2.7-1.	X	X	X	X	X				
	b. Emergency repressurization gases shall be provided to repressurize any normally pressurized, isolable module, independent of any other module, one time from zero to TBD psia. Exposure of the ECLS within the normally pressurized modules to a cabin	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline: [illegible] / Requirement or Mission Enabling Request	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
		SASP	SOC	SASP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 [illegible]
	pressure between zero and TBD psia shall not create hazards or cause damage to the ECLS or the Space Station									
	c. Provisions shall be made to prevent objectionable and noxious odors emitted in any location from being transmitted to any habitable location in the Space Station.	X	X	X	X	X				
	d. The atmospheric constituents, including harmful airborne trace contaminants, shall be monitored and controlled in each isolable pressurized habitable volume.	X	X	X	X	X				
	e. Atmospheric leakage of each module shall be less than 0.5 lb/day with a maximum of 5 lb/day for the total Space Station pressurized volume.	X	X	X	X	X				
	f. Overboard venting of gases shall be limited to those gases that will not degrade the performance of subsystem components exposed to space (e.g., solar cells and radiator surfaces). Gas venting that is permitted shall be minimized, controlled, and nonpropulsive.	X	X	X	X	X				
	g. Particulate matter filtration shall be provided in the ECLS for removal of airborne particles above TBD micrometer size.	X	X	X	X	X				
	h. The microbial concentration in the environment of each of the pressurized compartments containing crew quarters, laboratories, or experimental facilities shall be controlled.	X	X	X	X	X				
	i. The capability shall exist for dumping the atmosphere of a module overboard in the event of contamination or a fire in the module. Provisions to repressurize the evacuated modules shall be available from sources other than the aforementioned emergency gas supply. The number of repressurizations allowed will be determined by the criticality of each module.	X	X	X	X	X				
	j. The hydrogen contained in the ECLS subsystems shall not cause an explosive hazard if suddently leaked into the cabin atmosphere.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

Request Code No.	Technology Discipline: [illegible] — Requirement or Mission Enabling Request	Manned Platforms: Early LEO SASP	Early LEO SOC	Advanced LEO SASP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	[illegible]
	k. Crew-related consumable resupply shall be sized for TBD days based on the 24-hour nominal use rate. A TBD-day reserve of consumables shall be provided against the possibility that the normal resupply is interrupted.	X	X	X	X	X				
	Specific Requirements - Regenerative ECLS									
	The specific requirements that apply to the regenerative ECLS are the following.									
	a The cabin oxygen shall be supplied by electrolysis of water subject to trade studies.	X	X	X	X	X				
	b. Nitrogen shall be used as the diluent gas in the cabin atmosphere. The cabin pressure shall be compatible with that of the STS Orbiter and shall preclude the need for prebreathing prior to EVA.	X	X	X	X	X				
	c. A regenerative carbon dioxide removal system, which concentrates and collects the carbon dioxide for further processing for oxygen recovery, shall be provided to maintain the habitat module carbon dioxide partial pressure under 3.0 mmHG in nominal operation.	X	X	X	X	X				
	d. The humidity condensate collected in the carbon dioxide reduction and the other air revitalization processes shall be used first to produce potable quality water with chemical and physical treatments as necessary to satisfy potability requirements.	X	X	X	X	X				
	e. Urine and expended hygiene water shall be processed by a concept incorporating a phase change to produce potable quality water that is also acceptable for water electrolysis and other ECLS uses.	X	X	X	X	X				
	f. Effluent wash water must be adequately processed to ensure sterility and suitability as cleansing water as a minimum.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Reqmt Code No.	Technology Discipline: [illegible] — Requirement [illegible] Mission Enabling Reqmt	Manned Platforms: Early LEO SASP	Early LEO SOC	Advanced LEO SASP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	25 kw Pwr Mod
	Some environmental status monitoring instrumentation should be included in the HMF Examples are toxic compounds, water quality, microbial load (air, water, surfaces), noise, lighting, and radiation (space environment and onboard sources).	X	X	X	X	X				
	Physiological status monitoring is a necessary part of preventive medicine. Establishment of physiological norms for microgravity is important for health maintenance, diagnosis (e.g., deviation from the norm) and treatment (e.g., adjustment of medication dosage because of reduced body fluid). Some physiological monitoring will continue to be required throughout the Space Station era to determine whether physiological changes are within normal limits and, if not, to initiate appropriate countermeasures. The equipment needed is that also employed for diagnosis.	X	X	X	X	X				
	Medical Diagnosis									
	The HMF should have appropriate diagnostic equipment and a programmed medical diagnostic logic scheme. The interface would be accomplished on a display (e.g., CRT) and the program should include a broad spectrum of the most anticipated medical conditions.	TBD	TBD	X	X	X				
	Medical/Surgical Treatment									
	The Space Station should have a program treatment logic scheme that will follow the diagnosis. These treatment modalities will cover the broad spectrum of the most common treatment approaches.									
	a. Medication: Drugs and medications will be similar to the Space Shuttle medical systems (SOMS-A and SOMS-B) but with appropriate changes in medical supplies and equipment based on anticipated medical conditions and requirements. Provision for cold storage shall be provided.	X	X	X	X	X				
	b. Dental: Dental treatment capability will be similar to that used in Skylab. (Reference: Biomedical Results from Skylab, NASA SP-377)	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

Request Code No.	Technology Discipline: PERSO 1 — Requirement — Mission Enabling Request	Manned Platforms: Early LEO SASP	Early LEO SOC	Advanced LEO SASP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate-Size SASP	Advanced SASP	250 kw Pwr Mod
	c. Surgery. The Space Station should provide facilities for the treatment of fractures and minor and moderate injuries For patients with major trauma, relatively noncomplex facilities should be provided for stabilization until evacuation and ground-based treatment. (Major capability for thoracic or abdominal surgery will not be provided; therefore, there will be some risk of death. Body dispositioning procedures must be considered.) The Space Station health maintenance/surgical facility should have the following capabilities:			X	X	X				
	(1) An "operating table" with quick-release restraint systems to be used both by the treating medical crewman and by the injured or ill crewman.			X	[illegible]	X				
	(2) Equipment to monitor vital signs	TBD	TBD	X	X	X				
	(3) Intravenous fluid system	TBD	TBD	X	X	X				
	(4) Laminar flow workbench for the examination of bacterial growth plates, plating of microbial specimens, obtaining blood and urine specimens after they have been centrifuged, etc.	TBD	TBD	X	X	X				
	(5) Sterilization equipment for surgical instruments	TBD	TBD	X	X	X				
	Medical Records and Data									
	The Health Maintenance Facility should contain computer storage capability for biomedical data (medical records, diagnostic and treatment programs, physiological status, etc.). Such a computer should provide immediate accessibility of medical records on each member of the crew. Hard-copy output shall be available at the discretion of the operator. It is possible to share a computer with other onboard systems if the computer will be available at any time and a terminal is located in the facility. Distributed processing shall be considered to avoid single-point failures.			X	X	X				

Requirements Survey for Crew Systems Continued

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Report Code No.	Technology Discipline: [illegible] 1	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
	Requirement — Mission Enabling Request	SASSP	SOC	SASSP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Pwr Mod
	<u>Health Maintenance</u>									
	Crew Medical Training									
	At least one crewman should have extensive medical training or be a physician/surgeon. The primary medical crewman should also have appropriate dental training. A second crewman should have at least 100 hours of medical and dental training.	TBD	TBD	X	X	X				
	Facility									
	A Health Maintenance Facility (HMF) will be required. The HMF should be an area or "room" devoted to preventive medicine and diagnosis and treatment of illness/injury. It should be configured for convenient access to communications, instrumentation, and emergency treatment equipment.	TBD	TBD	X	X	X				
	Hyperbaric Chamber									
	Provisions should also be made to utilize one of the EVA airlocks as a hyperbaric chamber for treating decompression sickness (bends). This chamber should be capable of being pressurized at 45 psi and be large enough for the injured crewman, a medical attendant, and suitable monitoring equipment. An equipment pass-through airlock and viewing port should be provided. Alternatively, an easily destowable, inflatable hyperbaric chamber system should be considered.	X	X	X	X	X				
	Preventive Medicine									
	Exercise equipment will be required. Examples are a treadmill/bungee harness, a bicycle ergometer, and friction/spring-load exercisers. It is anticipated that about 1 hour per day of exercise may be required of each crewmember to ameliorate the adverse effects of long-duration exposure to microgravity. Provisions for reading or performing other compatible activities while exercising should be considered.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline: [illegible] 1 — Requirement ** — Mission Enabling Reqmt	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
		SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	[illegible] Fwd Mod
	<u>Critical functions</u> - The Space Station shall provide the capability for performing critical functions at a nominal level with any single component failed or with any portion of a subsystem inactivated for maintenance. The Space Station shall provide the capability to perform critical functions at a reduced level with any credible combination of two component failures, or with any credible combination of a portion of a subsystem inactivated for maintenance and failure of a component in the remaining portion of the subsystem. Capability shall be provided for performing critical functions at any emergency level until the affected function can be restored or the crew returned to Earth:	X	X	X	X	X				
	a. With any one module inactivated or isolated and vacated because of a malfunction or accident.	X	X	X	X	X				
	b. With any credible combination of a subsystem inactivated as a result of an accident and a portion of a redundant or backup system inoperative.	X	X	X	X	X				
	<u>Fire control</u> - The capability shall be provided for extinguishing any fire in the most severe oxidizing environment prior to failure of primary structural elements. Interior walls and secondary structure shall be self-extinguishing. All continuous nonmetallic materials shall be self-extinguishing items, where they are in use. (Note: The "most severe oxidizing environment" shall be consistent with qualification of materials and equipment; e.g., 30-percent oxygen partial pressure for cabin atmosphere.)	X	X	X	X	X				
	<u>Exposed surface temperatures</u> - Exposed surfaces within the habitable modules shall not exceed a temperature of 113° F (with a design goal of 105° F) and a low temperature of no less than 40°F.	X	X	X	X	X				
	<u>Module access</u> - Two or more entry/egress paths with emergency lighting shall be provided to and from every pressure-isolable volume (except for the logistics modules). The two paths shall be separated by airtight partitions, or shall be at least TBD feet apart, and shall lead to an area in which the crew can survive until Shuttle rescue or resupply. A design goal shall be to provide alternate escape routes that do not terminate into a common module area.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline [illegible] 1 — Requirement or Mission Enabling Request	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
		SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	[illegible]
	Drains, vents, and exhaust ports - Drains, vents, and exhaust ports shall prevent exhaust fluids, gases, or flames from creating hazards to personnel, vehicles, or equipment.	X	X	X	X	X				
	Subsystem activation/deactivation - subsystems shall be designed to prevent inadvertent or accidental activation or deactivation of functions or equipment that would be hazardous to personnel or the Space Station.	X	X	X	X	X				
	Hazards warning/corrective actions - The Space Station shall have the capability to provide crew warning of hazardous conditions and provisions for corrective action, emergency crew egress/escape or rescue, or mission termination. Pending further analyses and trade studies, automated safing and reconfiguration shall be adequate for up to TBD hours before requiring crew attention. For cases of automated switchover to redundant paths, confirmation of proper switchover or safing and the revised configuration status shall be provided.	X	X	X	X	X				
	Override capability - The crew must be able to override any automatic safing or switchover capability. All overrides shall be two-step operations with positive feedback to the initiator that reports the impending results of the override command prior to the acceptance of an execute command.	X	X	X	X	X				
	Command/control redundancy - Redundant accommodations for complete command and control of the Space Station shall be provided such that the primary control center has complete capability, but the backup control center will have, as a minimum, control of critical functions, with critical functions TBD. All controls of critical functions shall be operable by pressure-suited crewmen.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

Request Code No.	Technology Discipline [illegible] — Requirement or Mission Enabling Request	Manned Platforms — Early LEO — SASSP	Manned Platforms — Early LEO — SOC	Manned Platforms — Advanced LEO — SASSP	Manned Platforms — Advanced LEO — SOC	Manned Platforms — GEO — SOC	Unmanned Platforms — Early SASP	Unmanned Platforms — Intermediate SASP	Unmanned Platforms — Advanced SASP	Unmanned Platforms — 250 kw Pwr Mod
	a. Leisure and entertainment equipment, lounge areas, and snack foods and drinks shall be provided to enable the crews to refresh themselves during off-duty hours. These will include group functions as well as private leisure.	X	X	X	X	X				
	b. Exercise equipment and techniques shall be provided to enable the crews to retain the requisite physical body tone. This equipment/techniques can be utilized for recreation also. Considering that each crewmember may require one or more hours per day of exercise, provisions for simultaneous reading, television viewing, or music listening should be considered.	X	X	X	X	X				
	Crew Support									
	<u>Scheduling</u> - Single and multiple shift schedules may be used. Day-to-day planning of activities and assignments will be performed in the Space Station. Work and sleep/rest periods shall be scheduled to minimize fatigue and boredom.	X	X	X	X	X				
	The ground planning functions shall define objectives for block period of times. The flight crews shall make their daily work schedules based on general programs and checklists set in the computer and responding to ground defined objectives. The details of daily operations shall be defined by the flight crew.	X	X	X	X	X				
	<u>Emergency provisions and planning</u> - Requirements for emergency supplies and operations are TBD on the basis of crew size, mission length, and rescue capabilities.	X	X	X	X	X				
	<u>Man-machine interface</u> - The requirements for man-machine interfaces are those that provide for efficient, accurate operations of Space Station systems.									
	a. Anthropometric requirements - Crew systems shall be designed using the 5th- to 95th-percentile male and female NASA astronaut anthropometric strength and size measurements adjusted for 30-year growth trends.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline: [illegible] — Requirement or Mission Enabling Request	Manned Platforms — Early LEO — SASP	Early LEO — SOC	Advanced LEO — SASMP	Advanced LEO — SOC	GEO — SOC	Unmanned Platforms — Early SASP	Intermediate SASP	Advanced SASP	[illegible]
	b. Displays and controls: The main interface requirements for work station displays and controls will include the following.									
	(1) Multifunctional controls will be used for space and weight optimization wherever possible	X	X	X	X	X				
	(2) Character size, display brightness and contrast, and auditory characteristics are TBD.	X	X	X	X	X				
	(3) Control size, direction of motion, and types of controls to be used are TBD.	X	X	X	X	X				
	(4) Display format characteristics such as use of color, color coding, and graphical versus textual display are TBD.	X	X	X	X	X				
	(5) Feedback to the operator from controls, including tactile, visual, and auditory feedback requirements, are TBD	X	X	X	X	X				
	(6) Portable terminals to reduce weight and space requirements and to enhance flexibility of operations will be available.	X	X	X	X	X				
	(7) Remote manipulators and remotely piloted free flyers will provide adequate feedback to the operator, including where appropriate visual data, range/rate, and force/torque information.	X	X	X	X	X				
	(8) A standardized approach shall be established for design of all displays and controls used by the flight crew.	X	X	X	X	X				
	c. Information processing: System status will be available to the crew through an interactive data management system query language. The language will be easy to learn and adaptable to use for all systems. Inventory control shall be a part of this processing system.	X	X	X	X	X				
	d. Checklists and procedures: These will be stored in the DMS and accessed through general-purpose display devices wherever possible. The capability to update the DMS data base checklists with ease and safety is required.	X	X	X	X	X				
	e. Automation: Automated operating procedures and system control and monitoring will be provided where possible. Crew monitoring and override of automated procedures will be required.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

Request Code No.	Technology Discipline — FORM 1 Requirement ** *—Mission Enabling Request	Manned Platforms — Early LEO — SASP	Manned Platforms — Early LEO — SOC	Manned Platforms — Advanced LEO — SASP	Manned Platforms — Advanced LEO — SOC	Manned Platforms — GEO — SOC	Unmanned Platforms — Early SASP	Unmanned Platforms — Intermediate SASP	Unmanned Platforms — Advanced SASP	Unmanned Platforms — 250 kw Pwr Mod
	HABITATION/ACCOMMODATION									
	. Architecture									
	The geometric arrangement of compartments shall be such as to provide the necessary access and egress to all functions within the spacecraft. Traffic patterns shall be considered of prime importance. The separation of private or rest areas from noise-producing work areas shall be a high-priority consideration. A wardroom shall be provided that is sufficient to permit the nominal spacecraft crew to dine together. The wardroom shall provide a lounging area between mealtimes.	X	X	X	X	X				
	The interior appointments, including decoration and arrangement of furnishings, will be in accord with good architectural and interior design practice, i.e., provide visual space and stimulation. The intent is to provide the crews with soothing, restful surroundings. Provisions for rearranging decor should be considered.	X	X	X	X	X				
	Color and texture within the station shall be selected to provide visual orientation cues (local vertical), equipment stowage location cues, use location aids, aesthetic variety, and contrast for the crews. Good interior decorator practice shall be considered imperative in this area.	X	X	X	X	X				
	Stowage and retrieval considerations of all required crew support items as well as station systems spares will be a major factor in the interior arrangement of the station. The various stowage items shall be located as close to their use location as is practical. The problems of restowing items shall be considered when determining required stowage volumes. Color graphics shall be utilized as an aide in crew location of stowage items. Modular stowage lockers shall be incorporated into the overall interior arrangement of the station. Common latching devices shall be utilized throughout the station.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Reqmt Code No.	Technology Discipline FORM 1	Manned Platforms					Unmanned Platforms			
	Requirements ** **—Mission Enabling Reqmts	Early LEO		Advanced LEO		GEO				
		SASP	SOC	SASP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	200 kw Pwr Mod
	. Architecture (con't)									
	Significant protrusions along main traffic routes shall be avoided.	X	X	X	X	X				
	Interior Appointments									
	. The wardroom shall be equipped with chest high writing facilities and temporary storage. Basic Wardroom equipment shall be a computer terminal and a large screen video unit with a video cassette.	X	X	X	X	X				
	. The finish applied to walls, ceilings, and equipment in the vicinity of work stations and traffic areas shall be capable of withstanding significant abrasion and wear without noticeable deterioration.	X	X	X	X	X				
	. A color graphics system shall be adopted to indicate storage areas, affording easy recognition from any position, distance and lighting conditions.	X	X	X	X	X				
	. Tables, consoles, work stations and writing stations shall be chest high and equipped with foot restraints.	X	X	X	X	X				
	Stowage and Retrieval									
	. Drawers and cabinets shall be equipped with suitable restraints to allow easy access, removal and restowage of equipment.	X	X	X	X	X				
	. Equipment stowage provisions and restraints shall allow for easy identification of the stowed item prior to removal.	X	X	X	X	X				
	. Drawer stowage devices shall be equipped with internal lids to prevent small items from drifting from and behind drawers.	X	X	X	X	X				
	. Stowage areas shall be compartmented to aid in the control of equipment during crewmen stowage and removal of equipment.	X	X	X	X	X				
	Private Sleeping Quarters									
	. Private crew quarters shall be designed to be utilized with or without the sleep restraints. The private crew quarters shall be equipped for television viewing, individual bulletin boards, the ability to control temperatures and ventilation, trash stowage, stowage for personal items, and personalized decor.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

Reqmt Code No.	Technology Discipline: FORM 1 Requirement ** **--Mission Enabling Reqmt	Manned Platforms: Early LEO SASSP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASSP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Unmanned Platforms: Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Pwd Mod
	. Architecture (con't)									
	Private sleeping quarters shall be provided for each crewmember during standard operational phases of the station's mission lifetime. Sleeping quarters shall provide users with stowage facilities for clothing and personal items, music, recreational items, desk facilities, and a means of securing clothing removed for the sleep period. Sleeping quarters shall be quiet with no more than TBD noise permitted.	X	X	X	X	X				
	Observation windows will be required for work-related viewing. They will also be a prime source of recreation. Therefore, provision of the opportunity to rotate around the viewing port to allow body orientation to the Earth as appearing "down" should be considered.	X	X	X	X	X				
	. All walls and ceiling areas shall be usable for installation and stowage of equipment.	X	X	X	X	X				
	. Ceiling to floor heights shall be reduced to 6 feet whereever greater equipment installation and stowage volumes are desired.	X	X	X	X	X				
	. The Space Station wardroom area shall be designed and sized for use as a central meeting, eating and recreation area. Food storage and preparation shall not be disruptive to its use as a wardroom and recreation area.	X	X	X	X	X				
	. The wardroom shall double as an Emergency Medical Facility for the Initial Space Station with storage for an Emergency Health Maintenance Facility Unit. This unit will be available in the Growth Station as a first aid station.	X	X	X	X	X				
	. Waste Management Facilities shall be located away from the Food Preparation Area. Privacy shall be emphasized in the arrangement and location. A location near the private crew quarters is desirable.	X	X	X	X	X				
	. Temperature and Ventilation Controls shall be provided in the Waste Management Facilities.	X	X	X	X	X				
	. Normal Translation Traffic routes shall not interfere with the working, eating, sleeping or relaxation of crewmen.	X	X	X	X	X				
	. A clear zone shall be established continguous with each hatch and bulkhead opening, requiring all surfaces to be free of hardware protrusions, sharp corners and edges, and recesses or holes.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

Request Code No.	Technology Discipline: FORM 1	Manned Platforms					Unmanned Platforms			
	Requirement ** **-Mission Enabling Request	Early LEO		Advanced LEO		GEO				
		SASSP	SOC	SASSP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	280 km Fwd Mass
	. Architecture (con't)									
	. Private crew quarters ceiling shall be designed to permit easy ingress and egress to and from the sleep restraint.	X	X	X	X	X				
	. Private crew quarters shall be designed for convenient use with and without sleep restraint. Adequate volume shall be provided to allow rapid exit from sleep restraint.	X	X	X	X	X				
	. Private crew quarters ceiling to floor length shall exceed the sleep restraint length.	X	X	X	X	X				
	Windows									
	. The window design shall provide the capability for cleaning windows inside and out.	X	X	X	X	X				
	. The window design shall provide a positive means for removal of moisture from the space between multiple pane windows (assumes seal failure).	X	X	X	X	X				
	. It is desirable to integrate a viewing window into the private crew quarters and the wardroom area.	X	X	X	X	X				
	Mobility and restraint - The spacecraft shall provide crew and equipment with sufficient restraints and locomotion aids to enable the crews to function efficiently and effectively.	X	X	X	X	X				
	Locomotion: Handholds and pushoffs shall be incorporated into the interior arrangement of the spacecraft to permit crewmembers to push themselves to any area and to be able to halt their movement at any location. Equipment design must take into account that any surface or protrusion will be utilized as a locomotion aid.	X	X	X	X	X				
	Equipment located in traffic routes and work station areas shall be designed to accommodate crew movement. Equipment shall be designed to accommodate impact forces imparted by crewmen during translation movement.	X	X	X	X	X				
	Large items that require moving in the station shall have built-in handles or gripable structural or mechanical parts.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline: FORM 1 — Requirements or Mission Enabling Reqmt	Manned Platforms: Early LEO SASP	Early LEO SOC	Advanced LEO SASP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	200 kw Fuel Sled
	Valves, regulators, and other pressurized components shall have an ultimate factor of safety of 2.5. Pressure vessels shall be protected against over-pressurization or underpressurization that could be hazardous to personnel or the Space Station.									
	b. As a goal, all walls, bulkheads, hatches, and seals where integrity is required to maintain pressurization shall be accessible for inspection, maintenance, or repair by shirt-sleeved crewmembers.	X	X	X	X	X				
	Docking/berthing mechanisms accessibility - Inspection, maintenance, and repair of docking and/or berthing assembly mechanisms by shirtsleeved crewmembers shall be accommodated where practical.	X	X	X	X	X				
	Toxic materials -	X	X	X	X	X				
	a. Provisions shall be made for the containment and/or disposal of toxic contaminants. Hazardous or toxic fluid storage, conduits, and interconnects between modules shall be external to the pressurized volume. An exception may be made for flammable but nontoxic gases where the maximum possible quantity released by a leak cannot result in a flammable mixture.									
	b. Materials used in the habitable areas shall not outgas toxic constituents in the lowest pressure environments to which they will be exposed.	X	X	X	X	X				
	Materials contamination - Equipment or materials sensitive to contamination shall be handled in a controlled environment. Fluids and materials shall be compatible with the combined environment in which they are employed. Process specifications (TBD) shall define handling and application methods.	X	X	X	X	X				
	Hazardous accumulation of fluids - Provisions shall be made to prevent hazardous accumulations of gases or liquids within the Space Station (i.e., toxic, explosive, flammable, or corrosive). Detection of hazardous gases shall be required in critical areas and closed compartments to ensure that no hazardous conditions exist. As a goal, the Space Station system shall minimize the use of hazardous materials. Limitations regarding the accumulation of toxic and non-toxic gases are TBD.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Reqmt Code No.	Technology Discipline — FORM 1 Requirement ** *—Mission Enabling Reqmt	Manned Platforms: Early LEO SASSP	Early LEO SOC	Advanced LEO SASSP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	250 kw Pwr Mod
	Restraint aids: Properly designed and developed foot restraints are generally adequate to provide crewmembers with sufficient restraint to fulfill their functions. The foot restraint must be positive, passive, easily engaged and disengaged, lightweight, and fit the user's foot snugly. In areas or functions that require extreme steadiness, additional body restraints may be required.	X	X	X	X	X				
	Equipment restraints will be provided to anchor every item of use that is not permanently attached to the station. Such items as velcro patches, bungee cords, magnetic attachments, and the like are to be considered and utilized as restraints. However, this does not preclude additional restraint concepts (e.g., airflow tables).	X	X	X	X	X				
	Crew body restraints and work done in restraints shall not involve sitting, bending, stooping, or crouching.	X	X	X	X	X				
	A positive grid/shoe restraint system or equivalent shall be provided for crewmen use throughout the Space Station.	X	X	X	X	X				
	Restraint systems shall permit the crewmen to readily change position within reasonable working limits.	X	X	X	X	X				
	Work stations shall be designed for zero-g body positive with restraints adjustable in body length and torso length.	X	X	X	X	X				
	Whenever a crewman is required to engage or disengage foot restraints, suitable, grabable, conveniently located handholds shall be provided.	X	X	X	X	X				
	Adequate personnel restraints shall be provided in the Waste Management Area.	X	X	X	X	X				
	A simple readily applied and available restraint aid shall be provided for temporarily holding small items such as tools, bolts, screws, and washers.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Reqmt Code No.	Technology Discipline: FORM 1 Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO SASP	Early LEO SOC	Advanced LEO SASP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	250 kw Pwr Mod
	Equipment Restraints									
	Each work station shall be suitable equipped with positive restraints for conveniently holding check-lists, books, and manuals, open to a particular page and maintaining adequate visibility and lighting.	X	X	X	X	X				
	Clothing - The station will provide the crews with adequate clothing and the cleaning/washing facilities to maintain that clothing.	X	X	X	X	X				
	a. Duty garments. The clothing worn during the scheduled activities for the crew includes under and outer garments. The clothing shall provide the wearer with adequate pockets, etc., to serve as small equipment restraints. Flammability, cleanability, and wear resistance shall be considered. The change in body size in microgravity should be considered.	X	X	X	X	X				
	b. Off-duty clothing: The clothing worn during exercise and/or casual rest periods may include portions of the duty garmets and shall provide for variety.	X	X	X	X	X				
	c. Sleepwear: Sleeping garments shall be provided for the crews.	X	X	X	X	X				
	d. Protective clothing: Any protective clothing or garments deemed necessary for the heatlh hazard protection and well-being of the crews for particular missions shall be furnished.	X	X	X	X	X				
	Personal hygiene - The spacecraft shall provide facilities for body waste collection/disposal, personal cleanliness, and bathing. These systems shall be private and easy to use and clean.	X	X	X	X	X				
	a. Body waste collection: A means of collecting fecal matter and urine from crewmembers and disposing of that material shall be provided. The facilities shall be private, easy and efficient to operate, sized for 5th- to 95th-percentile female and male users, and easy and simple to maintain and keep clean.	X	X	X	X	X				
	The solid waste fecal-collector shall be oriented in the Earth-g position.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Reqmt Code No.	Technology Discipline: FORM 1 — Requirement ** Mission Enabling Reqmt	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
		SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	200 kw Fwd Mod
	b. Personal cleanliness: Facilities shall be provided to aid the crews to keep their hair, face, hands, and teeth clean and healthy at all times. Shaving facilities will be provided. The facilities shall be easy and efficient to operate and easy to maintain and keep clean.	X	X	X	X	X				
	A handwashing bubble shall be available for use outside the Waste Management facility.	X	X	X	X	X				
	c. Bathing: A full-body shower facility will be provided. This facility may also be used in case of chemical burns.			X	X	X				
	The shower facility shall satisfy the following requirements and characteristics. . Easy to use . Hot and cold running water controlled with a mixing valve . Permit hair and scalp washing . Use airflow system to remove water . Provide temperature controlled (heated) dressing area.									
	Housekeeping - The spacecraft shall be designed and arranged to facilitate keeping it clean. The equipment and expendables necessary to maintain this cleanliness shall be available to the crews.	X	X	X	X	X				
	a. Cleaning: All areas of the spacecraft shall be maintainable and cleanable. The equipment and supplies necessary for this cleaning shall be readily available to and usable by the crews.	X	X	X	X	X				
	All parts of the Waste Management system shall be designed to be easily disassembled for daily cleaning.	X	X	X	X	X				
	The Food Preparation and wardroom eating areas shall be designed to be easily cleaned following food spills.	X	X	X	X	X				
	b. Refuse collection and disposal: All the trash generated by the crew in using the various systems of the spacecraft shall be collected and disposed of. The collection points shall be readily accessible and located near the areas of greatest	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline FORM 1 — Requirement or Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASMP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Unmanned Platforms: Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Pwr Mod
	trash generation. The trash shall be treated with bactericides to prevent it from producing gas or odors. It shall be stored and returned to Earth via the logistics system.									
	Communications - This subsection concerns person-to-person communication within the station and with the ground and also man-machine interaction.	X	X	X	X	X				
	a. IVA communication: The station shall provide means to communicate readily from any point in the station to any other point. The noise levels shall be sufficiently low as specified TBD to allow face-to-face conversations. The IVA communications net shall be designed and located to prevent feedback and speaker interference.	X	X	X	X	X				
	The communication system intercom shall be flexible in operation and readily moveable. A duplex portable wireless intercom shall be considered as part of the intercom communication system.	X	X	X	X	X				
	b. Person-to-ground communication: Facilities shall be provided to enable any crewmember to readily talk privately with his family and/or friends on the ground. This will include radio communications and may include live two-way television viewing. Private medical conferences shall also be provided for.	X	X	X	X	X				
	c. External Communications: The communication system shall provide a method for signaling use state. A light or equivalent indicator shall show when the ground is transmitting and when the spacecraft is transmitting.	X	X	X	X	X				
	The communication system shall be designed to allow the operation to follow the information flow.	X	X	X	X	X				
	Crew Activity - Work/rest/leisure schedules shall be developed to effectively utilize the crew's time and capabilities and maintain their productivity. The necessary equipment shall be provided to accomplish this.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

Technology Discipline: POSSE ?

Request Code No.	Requirement ** Mission Enabling Reqmts	Manned Platforms: Early LEO SASP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Pwr Mod
	Failure tolerance - In the event of critical onboard subsystems failure, Space Station subsystems shall be designed to minimize risk of loss of modules, injury to the crew, or damage to the Orbiter and other vehicles.	X	X	X	X	X				
	a. No credible single Space Station failure, operational error, or radio-frequency (RF) Signal shall result in damage to Space Station or mission/payload equipment or in the use of emergency procedures equipment; some limited degradation in mission/payload accommodations, crew convenience/comfort, or Space Station attitude or orbit may be allowed.	X	X	X	X	X				
	b. No credible combination of two Space Station failures, operator errors, or RF signals shall result in the potential for crew injury or permanent loss of the Space Station or primary mission/payload capability, institution of emergency procedures/equipment may be necessary but no hazardous operational level will be reached.	X	X	X	X	X				
	System failure notification - All systems that incorporate an automated fail-operational capability shall be designed to provide crew notification and data management system cognizance of the malfunction until the anomaly has been corrected. Provisions shall be made to return crewmen who are incapacitated while performing EVA to the Space Station.	X	X	X	X	X				
	Crew radiation - The tentative standards for allowable radiation limits for the crew are defined in Table 2.6-1. Subsequent study must define whether the exposure levels established in table 2.6-1 are acceptable or whether the Standards of the National Commission Protection should be adhered to for Space Station activities. Radiation doses that affect personnel safety must be considered from all sources, including natural environment, external isotope and reactor sources (if any), electromagnetic, and solar cosmic radiation.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline — FORM 1 Requirements on Mission Enabling Request	Manned Platforms: Early LEO SASSP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASSP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Pwr Mod
	Materials radiation effects - Materials and components subject to insidious degradation in the Space Station ionizing radiation environment shall not be used where that degradation can cause or contribute to any crew hazard. Provisions shall be made to safely dispose of any spent radioactive materials such as nuclear waste from a reactor or from other nuclear resources.	X	X	X	X	X				
	Induced radiation limits - The allowable nonionizing radiation limits for the crew are as follows: a. RF energy: TBD b. Laser energy: TBD c. Microwave energy: TBD d. Electromagnetic radiation: Crew exposure to the Space Station electromagnetic environment shall not exceed recommended Occupational Safety and Health Administration (OSHA) standards.	X	X	X	X	X	X	X	X	X
	Storage containers - Potentially explosive containers such as high-pressure or volatile-gas storage containers shall be placed outside of and as far as possible from living and operating quarters. When ever possible, the containers shall be isolated and protected so that failure of one will not propagate to others. Specific safety storage and handling procedures shall be provided for the following materials: a. High-pressure fluids: TBD b. Volatile gases: TBD c. Subcritical fluids: TBD	X	X	X	X	X	X	X	X	X
	Cabin pressure vessels - a. All cabin pressure vessels shall be designed to leak-before-rupture criteria. A cabin wall puncture due to accident or collision shall not result in rupture. Conservative factors of safety shall be provided where critical single-failure-point modes of operation cannot be eliminated (pressure vessels, pressure lines, valves, etc.). Pressurized lines and fittings Size (inside diameter), in. — Ultimate factor of safety $\leq$ 1.5 — 4.0 $>$ 1.5 — 2.0	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline — FORM 1	Manned Platforms					Unmanned Platforms			
	Requirement ** Mission Enabling Request	Early LEO		Advanced LEO		GEO				
		SASSP	SOC	SASSP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw [illegible]
	Communications									
	A downlink system of communication should include image transmission so that the onboard medical crewmen may show images of an injured crewmember, microscope slides, or X-ray images while he is in private consultation with the ground physicians.	TBD	TBD	X	X	X				
	Other Considerations									
	a. Noise control: Provisions should be made for providing a low-noise environment in the HMF to facilitate acoustically coupled diagnostic procedures, (e.g., auscultation).	X	X	X	X	X				
	b. Contamination control: Biologically contaminated waste material should be disinfected as close as possible to its source prior to storage, processing, or disposal.	X	X	X	X	X				
	c. Equipment maintenance: Crews should be trained in making necessary repairs and maintenance on medical equipment. Equipment should be self-diagnosing via microprocessors and be of modular construction.	X	X	X	X	X				
	General Safety Requirements									
	The following requirements are defined or marked TBD using the most current information. Many of the technical areas are under study. The requirements will be modified and updated as the studies are completed.									
	The Space Station shall, in the following order of preference, (1) be designed to eliminate hazards by appropriate design measures; (2) prevent hazards through the use of safety devices or features; and (3) control hazards through the use of warning devices, special procedures, and/or emergency protection devices.									

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline: FORM 1 — Requirements — Mission Enabling Request	Manned Platforms: Early LEO SASMP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASMP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Pwr Mod
	Explosive devices - Provisions shall be made for arming explosive devices as near to the time of expected use as feasible. Provisions shall be made to promptly disarm explosive devices when no longer needed.	X	X	X	X	X				
	Battery location/design - Batteries shall be isolated and/or provided with safety venting systems and/or explosive protection.	X	X	X	X	X				
	Exposed power leads - The crew shall not be exposed to electrical power leads carrying higher than TBD volts at any frequency below TBD kilohertz without a minimum of TBD actions. The use of high-voltage direct current shall be avoided where possible. Ground-fault protection shall be provided for circuitry or power distribution buses directly accessible by the flightcrew.	X	X	X	X	X				
	Earth-to-Orbit Transportation (and Abort)									
	Space Station assemblies transported in the Orbiter payload bay shall, as a minimum, be designed to comply with the requirements of NHB TBD.	X	X	X	X	X				
	a. Ground system shall provide for safe disposal of hazardous vented or boiloff fluids. Detection of hazardous fluids shall be required in ground systems critical areas and closed compartments where such detection is critical to personnel and equipment safety or ground operations.	X	X	X	X	X				
	b. Space Station payloads shall be capable of safely recycling to a TBD time before launch hold.	X	X	X	X	X				
	c. The Orbiter Space Station payload shall not jeopardize the capability of the Orbiter to safely perform intact abort.	X	X	X	X	X				
	Assembly, Test, and Checkout On-Orbit									
	a. Deployment and initiation of operations considered hazardous shall be checked out from a safe location before exposing crewmembers to potential hazards. The Space Station shall be capable of being manned (shirtsleeve or intravehicular activity (IVA)) for performance of maintenance and station assembly tasks following any one component failure.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

Request Code No.	Technology Discipline: FORM 1 — Requirement — Mission Enabling Request	Manned Platforms: Early LEO SASP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Unmanned Platforms: Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Pwr Mod
	b. Safety requirements relative to an extravehicular activity (EVA) "buddy" system or for keeping EVA crewmen within visual range are TBD.	X	X	X	X	X				
	c. Each fluid delivery system must contain a minimum of three mechanically independent fluid control devices in series that remain closed during all ground and flight phases (except ground servicing) until reaching a safe distance from the Space Station or manned modules. A flow control device shall isolate the fluid tank(s) from the remainder of the distribution system. This isolation valve may be opened under provisions described in paragraph TBD. A minimum of one of the three devices shall be fail-safe; i.e., the device shall return to the closed condition in the absence of an opening signal. The opening of any flow control device shall not result in adiabatic detonation or uncontrolled release of the fluid. Each fluid system shall provide the capability to dump stored fluids in accordance with paragraph TBD when an emergency or abort situation arises.	X	X	X	X	X				
	d. Safety requirements applicable to the on-orbit servicing of solid propellant boosters, reaction control systems using monopropellants, and/or hypergolics shall be investigated and incorporated TBD.	X	X	X	X	X				
	On-Orbit Operations									
	Safety requirements applicable to all on-orbit missions and operations shall be investigated and incorporated TBD. Investigations for on-orbit operations include OTV interfaces, surveillance monitoring, maintenance, and resupply.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline: POSS 1 — Requirement or Mission Enabling Reqmts	Manned Platforms: Early LEO SASP	Early LEO SOC	Advanced LEO SASP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	280 hr Pad Mod
	Safing and crew rescue - The following capabilities shall be provided by the STS and Space Station.									
	a. Crew rescue by the Orbiter within TBD days. The need for a Space Station-based emergency vehicle for return to Earth shall be TBD.	X	X	X	X	TBD				
	b. Isolation of any module containing hazardous/toxic materials from the remainder of the Space Station within TBD seconds. Emergency conditions requiring isolation of a module shall be defined on a case-by-case basis.	X	X	X	X	X				
	c. A safe haven, isolatable from the rest of the manned station, capable of sustaining the flight-crew for TBD days. Emergency equipment including fire suppression, life support, and medical supplies will be provided within the manned safe haven and the manned Space Station modules.	X	X	X	X	X				
	d. Emergency provisions shall be developed and provided TBD.	X	X	X	X	X				
	e. Detection, containment (confining), and control (restoring to a safe condition) of emergencies such as fires, toxic contamination, depressurization, or structural damage. Specific decontamination procedures shall be provided for each emergency control to restore a safe operating condition.	X	X	X	X	X				
	Loss of module - In the event of a complete functional loss of any one module during all phases of the Space Station life, the Space Station shall maintain itself in a stable attitude and orbit for a period of TBD days for the initial operational crew size and TBD days, beginning at any point in the resupply cycle, for growth-level crew sizes. Independent habitable conditions such as atmosphere, food, water, waste management, health care, personal hygiene, sleeping provisions, communications, and command/control shall be provided in the remaining modules during these periods. This implies the capability of module isolation.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline: FORM 1 Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO SAASP	Early LEO SOC	Advanced LEO SAASP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	250 kw Pwd Mod
	<u>System Autonomy</u>									
	The Space Station shall be capable of operation independent of ground support ("operational autonomy"). For unmanned periods of operation, both during and subsequent to buildup, and for certain TBD contingencies, the Space Station shall accommodate ground control for system operation and monitoring. Real-time Space Station status information, on a selected basis, will be available to the ground. The management of Space Station systems will divide operations between the flight portion of the system and the ground so as to most effectively utilize the capabilities of each. Station system autonomy and onboard autonomy will be emphasized as a goal. System autonomy will minimize ground control of the station and onboard autonomy well minimize crew involvement in systems monitoring, allowing maximum use of the crew to perform high-return activities in support of user missions.	X	X	X	X	X				
	a. The capability to conduct near-term activity planning shall be required onboard the manned Space Station to the extent practicable.	X	X	X	X	X				
	b. Subsystem management, including consumables, shall be accomplished onboard the Space Station under the supervisory control of the flightcrew.	X	X	X	X	X				
	c. Maintenance of proper orbit parameters and orientation control shall be accomplished onboard the Space Station by the flightcrew or under their supervisory control.	X	X	X	X	X				
	d. All essential subsystems and the Space Station in its entirety shall be capable of being maintained in a quiescent state and reactivated by commands from the ground as well as from the flightcrew onboard the Space Station. Control from the STS shall not be a capability.	X	X	X	X	X				
	e. The ground shall provide TBD long-term trend analyses in support of flight hardware failure prediction, spares provisioning, and maintenance.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

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Request Code No.	Technology Discipline: FORM 1 Requirement ** *–Mission Enabling Request	Manned Platforms: Early LEO: SASP	Early LEO: SOC	Advanced LEO: SASP	Advanced LEO: SOC	GEO: SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	[illegible]
	f. The Space Station shall be designed to eliminate insofar as practicable the need for real-time monitoring and control of subsystem functions by the flightcrew or ground personnel ("machine autonomy"). Machine autonomy shall be optimized within the Space Station system and subsystems to also optimize crew involvement in failure detection, safing, and redundancy switching. Machine autonomy shall be implemented on the Space Station to increase crew efficiency, enhance payload operations, reduce ground support requirements, and increase system integrity.	X	X	X	X	X				
	g. Failure sensing and correction and unsafe-condition sensing shall be accomplished autonomously. High-level unsafe conditions (e.g., loss of Sun lock, potential loss of consumables, major power fault, etc.) shall initiate a safe-state establishment and wait for human involvement. Safe-state responses shall provide a safety net function for unanticipated failures and for any incorrect/false response by other autonomous features. Lower level unsafe conditions shall be corrected without affecting other Space Station activities.	X	X	X	X	X				
	h. Periodic and other nominal maintenance functions shall be performed by machine autonomy. These functions include but are not limited to inertial sensors calibration/initialization, battery conditioning, and articulation actuator calibrations.	X	X	X	X	X				
	i. Machine autonomy shall provide for resource management such as power management, battery energy accounting, and data storage management.	X	X	X	X	X				
	j. To the extent practicable, autonomous navigation and orbit control shall provide for orbit maintenance within prescribed bounds for a TBD time without ground or crew support.	X	X	X	X	X				
	k. Preprogrammed event sequences and/or routines shall be used to accomplish routine engineering and payload functions. The use of alternative payload sequences, to be selected autonomously based on the content of data being acquired, shall be accommodated.	X	X	X	X	X				

Requirements Survey for Crew Systems Continued

Request Code No.	Technology Discipline: [illegible] — Requirement or Mission Enabling Request	Manned Platforms: Early LEO SASP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Unmanned Platforms: Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: [illegible]
	l. Failure detection thresholds shall be capable of in-flight adjustment. Machine autonomous functions shall be capable of individual enable/inhibit control. Fault-condition response sequences shall be modifiable and expandable in flight, except when basic reliability would be compromised.	X	X	X	X	X				
	m. Machine autonomous functions shall be capable of being validated on the ground and verified periodically in flight. Loss of redundancy required for fault-correction routines to function properly shall be detected and displayed for the crew and ground personnel. During an anomaly response, key telemetry and configuration state history shall be stored. All steps taken by the autonomous recovery logic shall be included so that a clear history of the anomaly, its related effects, and the trace of the response software will be known.	X	X	X	X	X				
	OPERATIONS REQUIREMENTS									
	<u>Space Shuttle Orbital Operations</u>									
	Space Station Buildup									
	The delivery of various Space Station systems elements to orbit will be accomplished by the STS. Initial assembly, activation, checkout, and operational verification tasks will be shared by the STS in a Shuttle-tended mode, the Space Station flightcrew, and ground control. Crew occupancy will occur after the manned system is verified and will consist of a crew rotated by the STS every TBD days. As operational confidence is achieved in the various elements, ground support of their operation will be phased to an effective mix of onboard control and ground control. Expendables and spares will be periodically carried to the station in a logistics module by Shuttle resupply missions.	X	X	X	X	To LEO via STS To GEO via OTV				
	Orbital Operations									
	Orbital operations will include operating and servicing internal and externally attached experiments/payloads/laboratories, operating and servicing the unmanned platform-mounted experiments/payloads, servicing of payloads and free-flyers, test and deployment of payloads and upper stages, national security	X	X	X	X	TBD				

Requirements Survey for Crew Systems and for Flight Operations

Request Code No.	Technology Discipline — FORM 1	Manned Platforms					Unmanned Platforms			
	Requirement or Mission Enabling Request	Early LEO		Advanced LEO		GEO				
		SASP	SOC	SASP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Pwr Mod
	and commercial operations, and eventual large-scale construction/assembly of payloads. The manned Space Station will operate cooperatively with the unmanned platforms and their attached instruments, experiments, and payloads by providing systems monitoring and control, data and material collection, and systems/instrument replacement and refurbishment.									
	Space Station Orbital Operations Requirements									
	Evolutionary development - Evolutionary development during the life of the Space Station shall be required as a major operational and design consideration.	X	X	X	X	X				
	Operations - The manned station is intended to operate in the manned mode. Unmanned operations at the manned station will, as a minimum, consist of (1) maintenance of orbit, attitude, and systems, and (2) continuation of certain essential services to attached payload hardware.	X	X	X	X	X				
	The system shall operate in Shuttle-tended modes for material and crew resupply and for delivery of Space Station elements and delivery/return of payloads.	X	X	X	X	OTV-tended mode				
	Subsystems shall be automated to the fullest extent practical. The flightcrew or the ground shall be able to change automated sequences and limits in real time.	X	X	X	X	X				
	System design and operation shall allow use of the flightcrew for the performance of tasks when man's capability and utility could provide a cost-effective alternative to automation.	X	X	X	X	X				
	Management of Space Station system operations (both manned and unmanned elements) shall be divided between the flight system and the ground system to most effectively utilize the capabilities of each.	X	X	X	X	X				
	Continuous subsystem monitoring and control by either the flightcrew or the ground shall not be required for normal Space Station operations. Space station subsystems shall be designed such that any single credible failure will not require crew attention for a minimum of TBD hours and will not affect critical Space Station operations.	X	X	X	X	X				

Requirements Survey for Flight Operations

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Reqmt Code No.	Technology Discipline: FORM 1 — Requirements [illegible] Mission Enabling Report	Manned Platforms: Early LEO SASP	Early LEO SOC	Advanced LEO SASP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	[illegible] Pwd Mod
	The attached payloads may require some interaction by the Space Station. The extent of this interaction is payload dependent and will be determined on a payload-by-payload basis. Planning for the attached payloads will be done by the ground while control may be by either the Space Station or the ground.	X	X	X	X	X				
	Unmanned Platform Operations									
	Generally the operations scenario for the platforms and payloads is the same as for the Space Station. A Platform control center is the focal point for platform-related activity. It is possible that the platforms will be orbiting and operational before the Space Station. Platform maneuvers may be coordinated with the ground or be commanded by the Space Station without ground interaction.	X	X	X	X	X				
	Payloads									
	The term "payload" is used to identify all classes of instruments to be carried on-orbit by the Shuttle. The specific characteristics of the payload will depend on the details of the Space Station or an unmanned platform to which it is attached. Some payloads will be free-flyers (i.e., self-contained spacecraft not attached to the Space Station or to an unmanned platform). Other payloads will be attached to the Space Station or a platform, with the Space Station or platform acting as utility, providing services to the payload. Payloads must be compatible with the Space Station mission whether flown on the Space Station or on an unmanned platform.	X	X	X	X	X				
	Payload and Mission Operations Requirements									
	Operations - Manned station operations shall require operation of interior and attached payloads, satellite servicing, satellite construction, and mating with OTV's. OTV and TMS servicing and deployment/return and mission/experiment operations shall be conducted jointly with the unmanned co-orbiting platforms. Civil programs, international programs, and national security programs shall be supported.	X	X	X	X	X				

Requirements Survey for Flight Operations Continued

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Request Code No.	Technology Discipline — FORM 1 / Requirement — Mission Enabling Reqmt	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
		SASP	SOC	SASP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	25 kw Pwr Mod
	Provisions will be provided onboard to allow the crew to accomplish nearterm planning with a minimum of ground support.	X	X	X	X	X				
	Maintainability - Since systems will be maintained while on-orbit using both IVA and EVA, maintainability shall be a prime consideration in design of the system. Easy removal, repair, and/or replacement of Space Station equipment shall be required to the lowest practical level.	X	X	X	X	X				
	Critical systems shall be capable of undergoing maintenance without the interruption of critical services and shall be "fail safe" while being maintained.	X	X	X	X	X				
	The orbital replaceable hardware shall be designed for ease of on-orbit replacement. The hardware shall be designed or integrated to use common type fasteners, common connectors, and common tools and to utilize the same packaging as appropriate.	X	X	X	X	X				
	Command and data handling - Primary communications between the ground and the Space Station system shall be through the TDRS or its replacement system.	X	X	X	X	X				
	Logistics - Logistics for the orbital operation of the Space Station system shall consist of the orderly planning and execution for the resupply of consumables, delivery of spare/repair parts, propellant resupply, delivery or return of payloads or the delivery or return of any new or damaged element, and crew rotation.	X	X	X	X	X				
	Long-term activity planning shall provide the integration of requirements and schedules for the various logistics tasks. The STS will provide the means for the delivery to the station or the return to the ground.	X	X	X	X	STS to LEO; OTV to GEO				
	To minimize the logistics tasks, consideration should be given, as an example, to the level of the station elements systems' redundancy, consumables quantities onboard, and maintainability requirements in order to reduce the frequency of required ressupply or repair missions.	X	X	X	X	X				

Requirements Survey for Flight Operations Continued

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Request Code No.	Technology Discipline / FORM 1 — Requirement — Mission Enabling Request	Manned Platforms — Early LEO — SASP	Early LEO — SOC	Advanced LEO — SASP	Advanced LEO — SOC	GEO — SOC	Unmanned Platforms — Early SASP	Intermediate SASP	Advanced SASP	250 kw Pwr Sys
	A TBD level of redundancy shall be required in safety critical systems within the manned station.	X	X	X	X	X				
	Emergency equipment, including fire suppression, life support, and medical supplies, shall be required within the manned station.	X	X	X	X	X				
	Orbiter interaction - Orbiter interaction with the Space Station requires that the station be passive and that the Orbiter be the active docking vehicle. During periods of STS servicing/resupply, a coordination effort among the platform control function, the STS control center, the Space Station control function, the Orbiter, and the station shall be required.	X	X	X	X	OTV in lieu of Orbiter				
	Commonality - ORU's shall require standardization for direct interchangeability. Commonality of components, both hardware and software, shall be required to the extent possible. This applies to both flight and ground systems.									
	Management information capability - A management information capability shall be required onboard the Space Station and/or on the ground to provide systems maintenance and troubleshooting procedures, track consumable requirements, and repair and replace information.	X	X	X	X	X				
	Payload and Mission Operations									
	Manned Space Station Operations									
	The manned Space Station, operating in low Earth orbit, shall provide complete utilities and communication services for certain classes of attached payloads, such as life sciences and biological research. These payloads are tolerant of man's presence and, in fact, may utilize man as an integral part of the payload operations. Some payloads will require real-time diagnosis of science and subsequent reconfiguration, periodic collection of samples and the changeout of specimens/samples as well as the monitoring of key parameters.	X	X	X	X	X				

Requirements Survey for Flight Operations Continued

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Request Code No.	Technology Discipline: FORM 1 — Requirements — Mission Enabling Request	Manned Platforms: Early LEO SASP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOS	Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: [illegible]
	Experiment/payload operations at the manned station and within the system shall include the high capability for a high level of user participation.	Y	X	X	X	X				
	The system shall be designed and operated such that the flightcrew will have the ability to change planned activities in order to capture time-critical data from unexpected events.	X	X	X	X	X				
	Capability shall be provided for independent user operation and the monitoring of payloads consistent with safety and user compatibility constraints.	Y	X	X	X	X				
	<u>User interfaces</u> - Station system operations for experiments and payloads shall place a minimum number of requirements on users. Requirements shall be limited to those necessary for safety and user compatibility.	X	X	X	X	X				
	The Space Station and its operations shall provide simple, standard, stable requirements and interfaces of users of its services.	X	X	X	X	X				
	Operations and design shall provide a "user friendly" system to facilitate onboard operations by scientist or payload experts with a minimum of Space Station specialized training.	X	X	X	X	X				
	The Space Station system shall provide an optional capability for payloads to provide their own services such as computational, communication, ECLS, and/or power subsystems.	X	X	X	X	X				
	Payloads shall be serviced on-orbit by the Shuttle or manned Space Station and may be changed out as required. Payload changeout shall be performed by the Shuttle or by the Space Station as appropriate.	X	X	X	X	OTV or TMS servicing				
	The Space Station shall have the capability to service and repair satellites, payloads, and unmanned platforms.	X	X	X	X	X				
	<u>Autonomy</u> - For the unmanned platforms, TMS and OTV machine autonomy shall be required to the subsystem level.	X	X	X	X	X				

Requirements Survey for Flight Operations Continued

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Request Code No.	Technology Discipline — PHASE 1 Requirements [illegible] Mission Enabling Region	Manned Platforms — Early LEO — SASSP	Manned Platforms — Early LEO — SOC	Manned Platforms — Advanced LEO — SASSP	Manned Platforms — Advanced LEO — SOC	Manned Platforms — GEO — SOC	Unmanned Platforms — Early SASP	Unmanned Platforms — Intermediate SASP	Unmanned Platforms — Advanced SASP	Unmanned Platforms — 250 kw [illegible]
	<u>Ground Control/Support Operations</u>									
	Ground Control									
	Real-time ground support shall be provided to the STS and/or Space Station crew in the form of flight and systems monitoring and assistance during assembly and activation of each system element. This level of support will be maintained on a continuous basis until confidence has been gained in the orbital configuration operation. Subsequent monitoring will be limited to periodic checks. This procedure will be repeated for each new station element. This periodic monitoring approach will be used for both manned and unmanned station operations; however, voice communications with the manned station will be required.	X	X	X	X	X				
	<u>Ground Control Support Operations Requirements</u>									
	Initially, ground control shall provide for systems monitoring and support and then shall significantly reduce the real-time monitoring as the system becomes operational. Allocation of functions (from ground to flight) shall follow a planned phaseover as the operation matures.	X	X	X	X	X	X	X	X	
	Crew machine-designed interfaces for flight and training shall be based on standard work stations with features such as color graphics, callup of precoded routine procedures (and other software switches), and help and tutorial software.	X	X	X	X	X	X	X	X	
	Systems monitoring to augment crew capability shall be required during critical flight phases such as rendezvous and docking or during major system failure.	X	X	X	X	X	X	X	X	
	<u>Training</u> - The system shall be such that the need for specialized flightcrew training is minimized.	X	X	X	X	X				

Requirements Survey for Flight Operations Continued

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Reqmt Code No.	Technology Discipline: FORM 1 Requirement — Mission Enabling Reqmt	Manned Platforms: Early LEO SASP	Early LEO SOC	Advanced LEO SASP	Advanced LEO SOC	GEO SOC	Early SASP	Unmanned Platforms: Intermediate SASP	Advanced SASP	250 kw Power Mod
	Flight dynamics - A routine trajectory ground service shall be required once the Space Station is operational. Services to be performed by the Space Station or the ground include orbital maintenance of the station, OTV, and TMS maneuver planning and tracking, unmanned platform tracking, and satellite retrieval planning and tracking. (Orbital rendezvous with the station or other elements will continue as an STS function.)	X	X	X	X	X	X	X	X	
	Ground Operations									
	Objectives									
	The primary objective of the Space Station ground operations process is to ensure that the integrated flight and ground systems satisfy the applicable requirements. This objective will be accomplished by demonstrating that the performance of the combined Space Station subsystems, elements, payloads, and ground support equipment (GSE) meet established requirements and that the related interfaces are compatible and functional.	X	X	X	X	X				
	Ground Operations Requirements									
	Systems verification - Prelaunch operations shall provide verification that systems are launch ready and shall include interface verification to minimize on-orbit incompatibilities.	X	X	X	X	X				
	Physical and functional interfaces between Space Station elements and between payloads and the Space Station shall be demonstrated as compatible and functional before being committed to launch.	X	X	X	X	X				
	Self-test capability - Maximum use shall be made of flight system capability to reduce the requirements for GSE and other support during ground test of Space Station flight systems. Ground system simulation shall be required to support onboard problem resolution.		X	X	X	X				

Requirements Survey for Flight Operations and for Ground Operations

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DATA MANAGEMENT

Reqmt Code No.	Technology Discipline: FORM 1 — Requirement ****—Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASMP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Unmanned Platforms: Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Fwd Mod
	Architecture		Distributed Hierarchial 50% expansion		Distributed Hierarchial 50% expansion		Distributed	Distributed		
	Processor		Primary in one HM Backup in other Microprog entities Primary for day to day (32 bit)		Primary in one HM Backup in other Microprog entities Primary for day to day (32 bit)					
	Data Bus		Subsystem independent Error detect /recovery Standard interface F/O with NASA MWL terminal= baseline (contention)		Subsystem independent Error detect / recovery Standard interface F/O with NASA MWL terminal = baseline (contention)		Spacelab Equivalent			
	Experiment	Control/ monitor Sci experiments/payloads	-	Control/ monitor Sci experiments/payloads	TBD					
	Health Maintenance		-		Records Treatment					

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Requirements Survey for Data Management

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Reqmt Code No.	Technology Discipline: DATA MANAGEMENT — FORM 1 — Requirement ** **--Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP	Early LEO SOC	Advanced LEO SASMP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	Controls & Displays	Status monitor & control Crew interaction Auto fault detection & annunciation	Crew & other interface, eg, remote inputs for vehicle ops Man or auto overrides integrated C=baseline Input for subsystem color feedback multifunction tutorial Minimize interpretation	Status monitor & control Crew interaction Auto fault detection & annunciation	Crew & other interface eg, remote inputs for vehicle ops Man or auto overrides integrated C=baseline Input for subsystem color feedback Multifunction tutorial Minimize interpretation					
	Software	DP to support functions	Compatibility of processors Recording, TM, Status, faults, consumables, missions, SOC planning DP, on-board commands (ADA)	DP to support functions	Compatibility of processors Same S/W functions (ADA)		Controlled via PS			
	Mass Storage		Programs overlays maint/test Display formats Communication buffering Data set integrity Possible RAM backup		Programs Overlays Maint/test Display formats Communication buffering Data set integrity Possible RAM backup					

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Requirements Survey for Data Management (Cont'd)

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Reqmt Code No.	Technology Discipline: FORM 1 DATA MANAGEMENT	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
	Requirement ** **—Mission Enabling Reqmt	SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	Instrumentation/Recording		Gathered & preprocessed by subsys proc. Stored by DM proc Non subsys data via data bus		Gathered & preprocessed by subsys proc. Stored by DM proc Non subsys data via data bus					
	Common Data Base	Engr & Scientific 3.8×10^{10} bits 32 MBPS max record/ reproduce	RAM Multi-access some data	Engr & Scientific 3.8×10^{10} bits 32 MBPS max record/ reproduce	RAM Multi-access some data		Spacelab equivalent			
	Communication	16 chan multiplex 16 MBPS/chan max 58 MBPS total	Status to crew & ground Intra SOC Inter SOC I/O buffer to shuttle	16 chan multiplex 16 MBPS/ chan max 48 MBPS total	Status to crew & ground Intra SOC Inter SOC I/O buffer to shuttle		TDRSS via PS	TDRSS		
	Flight Control		Interface		Interface					
	Environmental Control & Life Support		Interface overrides		Interface overrides					
	Automated Power Systems Man		Interface Status data		Interface Status data					
	Propulsion		Interface		Interface					
	Propellant		-		Interface					
	S/C & Project Test/Checkout		-		Controls remote umbilical Exchange ground to test					

Requirements Survey for Data Management (Cont'd)

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Reqmt Code No.	Technology Discipline: FORM 1 DATA MANAGEMENT	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
	Requirement ** **—Mission Enabling Reqmt	SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	Construction & Flight Support		-		Remote umbilical OTV computer controls sys Local RF vs hard-wired commands from C&D or remote crew anti-collision					

Requirements Survey for Data Management (Cont'd)

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Reqmt Code No.	Technology Discipline: FORM 1 COMMUNICATIONS & TRACKING Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP [1]	Early LEO SOC	Advanced LEO SASMP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	CONCEPT DEFINITION STAGE									
2.008	Design With a 25% Growth Weight Margin	Not defined	X	Not defined	X	TBD				
2.010	Orbiter Cargo Bay Size Constraints . 15 feet diameter . 52-59 feet length	X	X	X	X	X				
2.011	Space Buildable/Deployable (Antenna)	X	X	X	X	X				
2.019	No Unique or Specialized Equipment For Deployment (In-space antenna buildup)	X	X	X	X	X				
2.020	Antenna Constraints . Moment of inertia symmetry about orbit plane . Max moment of inertia about axis normal to orbit plane . No persistent gravity gradient torques	Not defined	X	Not defined	X	TBD				
2.021	Provisions for subsystem services growth to meet mission needs	X	X	X	X	X				
2.025	90 day operations without resupply	X	X	X	X	TBD				
2.032	Design-capable for high inclination & geosynch orbits.	X	X	X	X	X				
2.033	10 year design service life	Not defined	X	Not defined	TBD	TBD				

1 Per SASMP Conceptual Design and Analysis Study, Oct 1981 - The SASMP Communications and Data Handling requirements can all be implemented with existing technology.

Requirements Survey for Communications and Tracking

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Reqmt Code No.	Technology Discipline FORM 1 COMMUNICATIONS & TRACKING	Manned Platforms					Unmanned Platforms			
	Requirement ** **--Mission Enabling Reqmt	Early LEO		Advanced LEO		GEO				
		SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
4.208	Medical Communications - Image transmission of injured crew, microscope slides, x-ray images for ground consultation. Medical records and data communications.	Not Defined	X	Not Defined	X	X				
7.103	Structures (antennas) designed to resist damage due to accidental crew impact (EVA).	X	X	X	X	X				

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Technology Discipline: FORM 1 COMMUNICATIONS & TRACKING

Reqmt Code No.	Requirement ** **--Mission Enabling Reqmt					Manned Platforms: Early LEO SASMP	Early LEO SOC	Advanced LEO SASMP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
7.601	Communications and tracking services between SOC and - . Shuttle . EVA's . OTV's . Free-flyers . Remote teleoperators . Relay Sats . Co-orbiting Sats					No OTV's	X	X	X	X				
	SOC COMMUNICATIONS LINKS PERFORMANCE REQUIREMENTS													
	Link-SOC To/From	Frequency* Band	Number** of Vehicles	Range Requests	Data Requests									
	Relay Satellite	S,Ku, or mm	1	38000 km	Di-Rate/ Low Rate Data, TV, Voice	No mmW	X	No mmW	X	X				
	Orbiter	S-band	2	2000 km	Vice & Data	X	X	X	X	X				
	EVA	Probably UHF	4	10 km	Duplex Voice; Low-Rate Data	X	X	X	X	X				
	OTV (Manned)	Ku-band or mm wave	2	38000 km- 2000 km- 100 km -	Voice, TLM, Low-Rate Data Ranging TV from OTV to SOC	-	X	-	X	X				
	OTV (Unmanned	Ku-band or mm wave	2	38000 km- 2000 km- 100km-	TLM, Low-Rate Data Ranging TV from OTV to SOC (remote piloting aid)	-	X	-	X	X				
	Free-Flyer	S-band, Ku-band or mm wave	4	2000 km- 100 km-	TLM, Low-Rate Data, Ranging TV from free-flyer to SOC	No mm W	X	No mm W	X	X				
	Tracking Radar	mm wave	Up to 10 targets	2000 km- 100 km-	long-range short-range mode	Not defined	X	Not defined	X	X				
	GPS	L-band		18500 km-	Navigation Data	Not defined	X	Not defined	X	x				

*Subject to Technology Developments.
**Simultaneous communications requirement.

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Reqmt Code No.	Technology Discipline: FORM 1 COMMUNICATIONS & TRACKING Requirement ** **—Mission Enabling Reqmt	Manned Platforms						Unmanned Platforms		
		Early LEO		Advanced LEO		GEO				
		SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
7.602	Duplex coms via synchronous satellite relay system with initial deployment	X	X	X	X	X				
7.603	1) SOC/TDRSS/Ground Links	S, Ku bands	S, Ku bands	S, Ku bands	mmW freq	S, Ku, mmW				
	2) SOC/Orbiter Links	S band	S band	S band	S band	S, Ku, mmW				
	3) SOC/Freeflyer & SOC/OTV links	S, Ku bands	S, Ku bands	S, Ku bands	mmW freq	S, Ku, mmW				
7.604	1) Transmission, Reception, Processing	X	X	X	X	X				
	. Voice	X	X	X	X	X				
	. Telemetry	X	X	X	X	X				
	. Commands	X	X	X	X	X				
	. Wideband Data	X	X	X	X	X				
	. TV	X	X	X	X	X				
	. Text	TBD	X	TBD	X	X				
	. Graphics	TBD	X	TBD	X	X				
	2) Secure Coms									
	. AJ . Anti-spoof	-	X	-	X	X				
	3) RFI Environment Capabilities	X	X	X	X	X				
7.605	Receive & Process GPS Signals for NAV		X		X	X				

Requirements Survey for Communications and Tracking (Cont'd)

Reqmt Code No.	Technology Discipline: FORM 1 COMMUNICATIONS & TRACKING Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASMP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Fwd Mod
7.606	Acquisition & Tracking -									
	. Traffic Control	-	X	-	X	X				
	. Rendezvous & Docking	X	X	X	X	X				
	. Orbital Ephemeris Generation	-	X	-	X	X				
	Capabilities - . 100% coverage within +/- 15 of orbit plane . 75% coverage for balance of sphere, except . 100% coverage within 8 Km for free-flyers with propulsive stages . Monitor up to 10 targets . Whole-sky sweep to 2000 Km in 2 minutes . Path prediction computation for multiple target scan	Not defined	X	Not Defined	X	TBD				
	Parameter / Long Range Mode / Proximity Mode Range / 2000 Km / 100 Km Range Accuracy / 1 Km / 10 Km Velocity Accuracy / 1 m/sec / 0.1 m/sec Angular Resolution / 25 mr / 10 mr									
7.607	1) Voice Conferencing	X	4 EVA's, manned spacecraft, ground net, & SOC	X	Same as early LEO SOC	Same as early LEO SOC				
	2) Recognize, process, amplify, mix, synthesize, switch, and distribute voice to and from internal user locations, hardline, and rf interfaces.	No recognition or synthesis	X	No recognition or synthesis	X	X				

Requirements Survey for Communications and Tracking (Cont'd)

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Reqmt Code No.	Technology Discipline: FORM 1 COMMUNICATIONS & TRACKING — Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASMP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Fwd Mod
7.608	SOC - Ground & SOC - Manned spacecraft duplex voice coms from any pressurized volume which might serve as emergency retreat.	From designated "Safe Haven" only	X	From designated "Safe Haven" only	X	X				
7.609	No attitude restraints to maintain RF links	TDRSS links only	X	TDRSS links only	X	X				
7.610	Operational Requirements	Not defined		Not defined						
	SOC RF COMMUNICATION LINKS OPERATIONAL REQUIREMENTS									
	SOC Comm; Usage; Interruptible									
	To/From Relay Satellite; Continual; Yes		X		X	X				
	To/From Orbiter; Continual During Rendezvous Docking, Separation; Except During Docking		X		X	X				
	To/From EVA; Continuous During EVA; No		X		X	X				
	To/From OTV; Continual During OTV Launch and Recovery Operations; Except During Docking		X		X	X				
	To Free-Flyers; Occasional (Operations, Orbit Maintenance, Recovery); Except During Docking and Maneuvering		X		X	X				
	From Free-Flyers; Continual (Status); Yes		X		X	X				
	Surveillance Radar; Continual; No		X		X	X				

Requirements Survey for Communications and Tracking (Cont'd)

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Reqmt Code No.	Technology Discipline: FORM 1 COMMUNICATIONS & TRACKING Requirement ** **–Mission Enabling Reqmt	Manned Platforms						Unmanned Platforms		
		Early LEO		Advanced LEO		GEO				
		SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
7.611	SIMOP Requirements	Not Defined	X	Not Defined	X	X				

SIMULTANEOUS SOC COMMUNICATION LINKS

SOC Comm To/From	Simultaneous Elements: Relay SAT	Orbiter	EVA	OTV	Free Flyer	GPS
Relay Sat		X	X	X	X	X
Orbiter	X		X		X	X
EVA*	X	X		X	X	X
OTV	X		X		X	
Free Flyers*	X	X	X	X		X
GPS	X	X	X	X	X	

*Multiple-TBD
X-Indicates Simultaneous Operations

Requirements Survey for Communications and Tracking (Cont'd)

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Reqmt Code No.	Technology Discipline: FORM 1 COMMUNICATION & TRACKING — Requirement ** **–Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP	Early LEO SOC	Advanced LEO SASMP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
7.612	Com link through docking interface with com system of attached vehicles	Not defined	X	Not defined	X	X				
7.613	1) Internal coms available in all habitable areas (including EVA airlocks & active dock ports)									
	. Duplex voice	X	X	X	X	X				
	. Caution & warning signals	Not defined	X	Not defined	X	X				
	. PA	X	X	X	X	X				
	. Closed circuit video	Not defined	X	Not defined	X	X				
	. Wireless voice com	-	X	-	X	X				
	2) ICS not interrupted or degraded in surviving modules due to malfunction of other modules.	Not defined	X	Not defined	X	X				
	3) Umbilical-free (wireless) voice coms within and between modules	-	X	-	X	X				
7.614	Common time-base for all C & T elements, and/or time-tagging of all information	-	X	-	X	X				
7.615	1) TV, text, graphics - generation, processing, distribution, transmission, recording, reception	X	X	X	X	X				
	2) CCTV for crew entertainment, docking support, area monitoring	Not defined	X	Not defined	X	X				
	3) Hardcopy printout - ground commanded and crew initiated.	Not defined	X	Not defined	X	X				
7.616	BIT throughout subsystem design . Failure detect at functional path level in flight and fault isolation. . Continuously monitoring BITE, and test points at electrical interfaces.	Not defined	X	Not defined	X	X				

Requirements Survey for Communications and Tracking (Cont'd)

Reqmt Code No.	Technology Discipline: FORM 1 COMMUNICATION & TRACKING	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
	Requirement ** **—Mission Enabling Reqmt	SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
7.617	All equipment capable of quiescent (powered-down) configuration and reactivation by SOC or ground command	Not defined	X	Not defined	X	X				
7.618	Radar Enhancement Devices (RED) or active transponders to assist vehicles using active docking procedures	Not defined	X	Not defined	X	X				
7.619	Narrowband and wide band engineering data: generation, processing, telemetry transmission	X	X	X	X	X				
7.620	Subsystem Operational data: generation, processing, telemetry transmission	X	X	X	X	X				
7.621	1) LRU level planned/unplanned maintenance. 2) LRU's designed for easy crew replacement. 3) External LRU's shall have EVA servicing provisions	Not defined	X	Not defined	X	X				
7.622	1) C&T system shall interface with the Integrated Entry & Display System via C&T processor/controllers.	X	X	X	X	X				
	2) C&T processor/controllers shall provide									
	. Status monitoring	X	X	X	X	X				
	. Automatic configuration management	Not defined	X	Not defined	X	X				
	. Fault Isolation	X	X	X	X	X				
	. Display/control functions as req'd for ops.	X	X	X	X	X				
7.623	Reliability requirements met through long-life design, scheduled maintenance and repair, and redundancy	X	X	X	X	X				

Requirements Survey for Communications and Tracking (Cont'd)

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ELECTRICAL POWER SYSTEM

Reqmt Code No.	Technology Discipline — FORM 1 Requirement ** **—Mission Enabling Reqmt	Manned Platforms — Early LEO — SASMP	Manned Platforms — Early LEO — SOC	Manned Platforms — Advanced LEO — SASMP	Manned Platforms — Advanced LEO — SOC	Manned Platforms — GEO — SOC	Unmanned Platforms — Early SASP	Unmanned Platforms — Intermediate SASP	Unmanned Platforms — Advanced SASP	Unmanned Platforms — 250 kw Fwd Mod
	Power System (Total) PM = Power Module SM = Service Module HM = Habitat Module	PM-Phase I . 12.5 KWe .16,600 lbs . 25' long . life 5 yrs .	. Life 10 yrs . Continu-ous . Capable of growth . Support 50 KWe load plus experi-ments	PM Phase II . 25 KWe . 33,200 lbs Phase III . 50 KWe . 49,800 lbs . life 5 yrs	. life 10 yrs . Capable of growth . Support 50 KWe load plus experi-ments	. Life 10 yrs . Capable of growth . Load TBD	PM . 25 KWe 12.5 KWe option	PM . 25 KWe . 12.5 KWe option	PM . 25 KWe . 12.5 KWe option	12738 lbs
	Solar Array	PM-Phase I . Deploy-able/Con-structi-ble . 298'x16' each PM unit . To support 12.5 KWe (load + battery recharg-ing)	. Deploy-able/con-structi-ble . To support 50 KWe load plus battery recharg-ing . On tunnel connect-ing SM & HM	PM-Phase II . Deploy-able/con-structi-ble . 2 units 298'x16' Phase III . To support 25 KWe (load + battery recharg-ing)	. Deploy-able/con-structi-ble . To support 50 KWe load + TBD Experiment + battery recharg-ing . On tunnel connect-ing SM & HM	. Deploy-able/con-structi-ble . To support TBD load + battery recharg-ing . On tunnel connect-ing SM & HM	. Deploy-able/con-structi-ble . To support 25 KWe (load plus battery recharg-ing)	. Deploy-able/con-structi-ble . To support 25 KWe (load plus battery recharg-ing)	. Deploy-able/con-structi-ble . To support 25 KWe (load plus battery recharg-ing)	. Deploy-able/con-structi-ble . SEPS Tech-nology . Each wing 28.5'x129.5' . Two wings . Two blan-ket/wing . 2128 lbs/ 2 wings . Total out-put 66.7 KWe at 60°C.
	Energy Storage . Nickel Cadmium Batteries . Energy Momentum Wheels . Nickel Hydrogen Batteries . Regenerable Fuel Cells	. User not supplied? Not de-fined	. Ni-H2 baseline . Fuel cells alternate . Flywheels alternate	. User supplied? Not de-fined	. Ni-H2 baseline . Fuel cells alternate . Flywheels alternate	. Ni-H2 baseline . Fuel cells alternate . Flywheels alternate	. User supplied	. User supplied	. User Supplied	. Ni-Cd . 60 modules (12 batt-eries) . 7440 lbs . 95.4 KWH . 60 AH cells . DOD 20%

Requirements Survey for Electrical Power System

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ELECTRICAL POWER SYSTEM

Reqmt Code No.	Technology Discipline: FORM 1	Manned Platforms					Unmanned Platforms			
	Requirement ** *—Mission Enabling Reqmt	Early LEO		Advanced LEO		GEO				
		SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	30 Volt Regulator									. 12 units . 660 lbs . 3800 w
	120 Volt Regulator									. 3 units . 165 lbs . 108 w
	Solar Array Drive & Power Transfer Assy									. 2 units . 380 lbs . 336 w
	Solar Array Distribution									. 1 unit . 30 lbs . 112 lbs
	Solar Array Drive Electronics									. 1 unit . 30 lbs . 10 w
	Cables and Connectors									. 750 lbs
	Power Interface Distribution									. 1 unit . 175 lbs . 306 w
	Payload Distribution (30V)									. 1 unit . 110 lbs . 302 lbs
	Payload Distribution (120V)									. 1 unit . 26 lbs . 108 lbs
	Subsystem Distribution									. 1 unit . 50 lbs . 28 w
	Subsystem Inverter		DC to 115/ 200V, 30,400 Hz, TBD KW		DC to 115/ 200V, 30,400 HZ TBD KW	DC to 115/ 200V, 30,400 Hz TBD KW				. 3 units . 45 lbs . 90 w
	Rack Distribution									. 3 units . 90 lbs . 50 w

Requirements Survey for Electrical Power System (Cont'd)

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ELECTRICAL POWER SYSTEM

Reqmt Code No.	Technology Discipline: FORM 1 Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO: SASMP	Manned Platforms: Early LEO: SOC	Manned Platforms: Advanced LEO: SASMP	Manned Platforms: Advanced LEO: SOC	Manned Platforms: GEO: SOC	Unmanned Platforms: Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Fwd Mod
	Power Distribution		. Protection . 120V DC on solar array . 28V DC for batt. chg. . 115/200V AC, 30, 400Hz. TBD KVA . 50 KW at bus		. Protection . 120V DC on S/A . 28V DC for batt. chg. . 115/200V AC, 30, 400Hz, TBD, KVA . 50 KW at bus + experiments	. Protection . TBD DC . TBD AC . TBD KW	. 30V DC/ 6 KW . 120V DC/ 6 KW	. 30V DC . 120V DC	. 30V DC . 120V DC	. Subsystem sec 30V DC, 2.25/3 KW . Low voltage, 30V DC single pt. gd. . High voltage grounding TBD . 23-32.5V DC . Low V = 25/35.5KW . High V = 25/27 KW
	Solar Array Mast									
	Automatic Power System Management (APSM)		. Required APSM . In SM&HM		. Required APSM . In SM&HM	. Required APSM . In SM&HM				
	Rotating Joint at Solar Arrays	PM-Phase I . 360° rotation . 7 KWe power transfer . DC sliprings	. Slipring/brush baseline . Rotary XFMR Alternate	PM-Phase II . 360° rotation . 13 KWe power transfer Phase III . 360° rotation . 13 KWe power transfer . DC-sliprings	. Slipring/brush baseline . Rotary XFMR alternate	. Slipring/brush baseline . Rotary XFMR alternate	. 360° rotation . Slipring/brushes	. 360° rotation . Slipring/brushes	. 360° rotation . Slipring/brushes	. 360° rotation . Slipring/brushes
	Battery Charger		. 28V DC . Convert from 120V DC							. 12 units . 660 lbs . 1843 w

Requirements Survey for Electrical Power System (Cont'd)

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ELECTRICAL POWER SYSTEM

Reqmt Code No.	Technology Discipline: FORM 1 — Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP	Early LEO SOC	Advanced LEO SASMP	Advanced LEO SOC	GEO SOC	Unmanned Platforms: Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	Emergency Power		. 504 hrs duration for critical loads . Primary power system provide 1/2 of normal output		. TBD hrs duration for critical loads . Primary power system provide 1/2 of normal output	. TBD hrs for critical loads . Primary power system provide 1/2 of normal output				

Requirements Survey for Electrical Power System (Cont'd)

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Reqmt Code No.	Technology Discipline — FORM 1 Requirement ****—Mission Enabling Reqmt	Manned Platforms 1980 Early LEO SASMP	 Early LEO SOC	 Advanced LEO SASMP	 Advanced LEO SOC	 GEO SOC	Unmanned Platforms 1980 Early SASP	 Intermediate SASP	 Advanced SASP	 After 1990 250 kw Fwd Mod	1985 25 kw PWR SUPPLY
	Propulsion System Attitude Control System (ACS)		Momentum exchange & RCS			Momentum exchange & RCS	Magnetic torquers				
	Reaction Control System (RCS)		o Attitude maneuvers o Orbit maintenance o Baseline Hydrazine o 90 day reserve o Array of 30 lb thrust thrusters on booms			o Attitude maneuvers o Orbit mainten-ance o 90 day reserve					o Common with propulsion system o 7.4 lbs per thruster o 8 thrusters o Hydrazine o Isp=223 o Max on-time=3280 sec.
	Propulsion System	o 90 day reserve o Reboost every 15 days o 1 year life	o Deorbit capability o Orbit makeup o Thrust= 900 lb.min. o 90 day reserve (4850 lbs)	o 90 day reserve o Reboost every 15 days.		o Deorbit capability o Orbit makeup o Thrust= 900 lbs min. o 90 Day reserve (4850 lbs)					o Reboost at reg-ular intervals o 40 lbs per thruster o 4 thrusters o Hydrazine o Isp=235 o Max on-time= 5100 sec. o 1200 lbs of hydra.

Requirements Survey for Propulsion

GUIDANCE & NAVIGATION TECHNOLOGY

Reqmt Code No.	Technology Discipline — FORM 1 Requirement ** **—Mission Enabling Reqmt	Manned Platforms					Unmanned Platforms			
		Early LEO		Advanced LEO		GEO				
		SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	NCR 160944 SOC 1/82									
7.6	Maintenance of Communication Tracking			Provide Co-Orbital Ephemeris Data			Autonomous Tracking			
	Acquisition and Tracking of Other Vehicles For Docking or Traffic Control (Collision Avoidance)			Formation Flying						
7.7	Docking and Berthing of 1 or More Spacecraft With Platform	Shuttle Docking		Auto Rendezvous and Docking Required For Unmanned Vehicles			Shuttle Docking		Auto Rendezvous and Docking to Unmanned Platform	
	(Also G9245 SASP Momentum Management/Orbit Management and Berthing)									
	Impact of Large Vehicle on Orbit Determination									
7.8	Flight Control/Propulsion and Maneuvering of Platform - State Vector Determination and Update - Fine Pointing Requirements	Fine Pointing From Experiments								
8.0	Manned/Unmanned Flight Support Operations - SOC Based	Launch Operations From Platform Payload Transfer Operations								

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Reqmt Code No.	Technology Discipline — FORM 1 ATTITUDE CONTROL	Manned Platforms						Unmanned Platforms		
		Early LEO		Advanced LEO		GEO				
	Requirement ** **—Mission Enabling Reqmt	SASMP	SOC	SASMP	SOC	SOC	Early SASP	Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	Provide following control modes									
	Velocity control									
	Orientation for Docking	X m/s	X m/s				X m/s			Reboost
	Berthing	X	X	X	X		X	X	X	X
	Buildup									
	Science Support									
	Solar Array Pointing	X	X	X	X		X	X	X	X
	Sattelite Servicing			X	X					
	Module control during buildup	PM	SM HM	PM	SM HM					
	Pointing Accuracy		5 degrees nominal TBD deg/sec . 3 deg . 005 deg/ sec for docking				.3° to 2° without pointing system			.3 degrees without payload sensors
	Maneuver Rates									1.5 to 8°/min nominals 3.8 to 20°/min max in sortie mode 20 to 45°/min nominal 50 to 113°/min in free flying mode
	Control Stability		Stable control with low frequency structure (>~.04Hz)		Stable control with low frequency structure (>~.04Hz)		1 min			~1 min
	Stability Margins									

Requirements Survey for Attitude Control

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Reqmt Code No.	Technology Discipline: FORM 1 ATTITUDE CONTROL Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP	Early LEO SOC	Advanced LEO SASMP	Advanced LEO SOC	GEO SOC	Early SASP	Unmanned Platforms: Intermediate SASP	Advanced SASP	250 kw Fwd Mod
	Control System Bandwidth									
	Attitude Determination		Support determination of SOC state vector		Support determination of state vector		Precision attitude determination thru payload sensors			
	Control Disturbances									
	Environmental (aerodynamic, gravity, gradient, etc)	all								
	Crew motion	X	X	X	X					
	Docking	X	1	X	1					
	Berthing	X	X	X	X					
	Construction			X	X					
					Propellant transfer					
				Tethered platform						
			Momentum desaturation		Momentum desaturation					Momentum desaturation
	Provide adequate control torques over a range of c.g. locations and mass properties	X	X	X	X		X	X	X	Solar panels partially stored
	Life		10 years with maintenance							5 years with orbit maintenance

1 Axial closing velocity .16-.5 ft/sec
Lateral velocity 2 ft/sec
Angular velocity .6 deg/sec
Lateral misalignment 0.75 ft
Angular misalignment 5 deg roll
6 deg pitch/yaw

Requirements Survey for Attitude Control (Cont'd)

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Reqmt Code No.	Technology Discipline: FORM 1 — ATTITUDE CONTROL Requirement ** **—Mission Enabling Reqmt	Manned Platforms: Early LEO SASMP	Manned Platforms: Early LEO SOC	Manned Platforms: Advanced LEO SASMP	Manned Platforms: Advanced LEO SOC	Manned Platforms: GEO SOC	Unmanned Platforms: Early SASP	Unmanned Platforms: Intermediate SASP	Unmanned Platforms: Advanced SASP	Unmanned Platforms: 250 kw Fwd Mod
	PAYLOAD SUPPORT									
	Precision Pointing							1.5 sec instrument pointing sec with image motion compensation		
	Materiels Processing	Acceleration <10-4 g's		Acceleration <10-4 g's						Accelerations 2x10-4 g's sortie mode 4.2 x10-7g's free flying
	AUTONOMOUS OPERATION		21 day stability during buildup FID Fail operational fail safe		90 day stability during buildup FID Fail operational fail safe					

Requirements Survey for Attitude Control (Cont'd)

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3.0 CANDIDATE BENEFITS/READINESS SURVEY (FORM 2)

This section presents the data sheets filled in by technical evaluators to define technology advancement benefits anticipated, to enter the estimated technology advancement criticality category (see table 3.0-1), to specify trades and options which are applicable to each technology candidate, and to list the relevant technology readiness levels (see table 3.0-2).

These Form 2 sheets are provided for the following technology disciplines:

- Thermal control
- Structure, Mechanisms and Materials
- Crew systems
- Flight Operations
- Ground Operations
- Data Management
- Communications and Tracking
- Electrical Power
- Propulsion
- Guidance and Navigation
- Attitude Control

The benefits anticipated are identified with respect to early or advanced manned platforms and with respect to early, intermediate or advanced unmanned platforms.

Table 3.0-1. Technology Criticality Category Code Definitions

CODE	CALL-OUT	DEFINITION
A	New Tech Required	Requires new technology to satisfy program objectives/mission requirements. (Enabling)
B	Tech Adv Required	Requires technology advancement to satisfy the program objectives/mission requirements (Enabling)
C	Tech Adv Desirable	Technology advancement is highly desirable; however, off-the-shelf technology may suffice, but with some performance degradation. (Enhancing)
D	Off-the-Shelf	Off-the-shelf technology is satisfactory.

Table 3.0-2. Technology Readiness Level Code Definitions

DE	CALL-OUT	DEFINITION
	Basic Principles	Basic principles have been observed and reported
	Concept Designed	Conceptual design has been formulated.
	Concept Validated	Conceptual design has been validated or tested analytically or experimentally.
	Critical Function Demonstrated	Critical function or characteristic has been demonstrated.
	Breadboard Lab Tested	Component or breadboard has been tested in relevant environment.
	Model Lab Tested	Prototype/engineering model has been tested in relevant environment.
	Space Tested	Prototype/engineering model has been tested in space.
	On-the-Shelf	Item is on-the-shelf and is qualified or is qualifiable with minor modifications

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FORM 2

Technology Discipline: Thermal Control (T/C) — Technology Advancement Goal	Benefits	Applicable to: Manned Platforms — Early LEO	Manned Platforms — Adv LEO	Manned Platforms — Adv GEO	Unmanned Platforms — Early LEO	Unmanned Platforms — Int LEO	Unmanned Platforms — Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o 10 Year Life T/C System	o Reduced cost of maintenance o Minimize redundancy & mass of T/C system	X	X	X	X	X	X	A	o Select best concepts o Materials development o Component development o Radiators o Transport loop o Pumps o Heat Exchangers o Controls o Fabricate prototype system o Conduct life test on ground o Conduct zero "G" performance tests	o Stable radiator coating o Liquid loop o Heat pipes o Hybrid pump-assisted heat pipe system o Pumped two-phase system	1 7 2 2 2	o Current coating degrade & are subject to contamination o Long life not demonstrated o Long life & high transport capacity major issues o Pumps, materials compatibility, fluid contamination are issues o Pumps, fluid phase control & liquid positioning are issues
o Modular Growth Capability o Power 25 KW→250 KW o Module & Payload Addition	o Maintain central thermal bus & control system o Eliminate redundant T/C components o Reduce system mass & volume	X	X	X	X	X	X	B	o Develop concepts for: o Adding payload heat sinks o Adding radiator elements or increasing area o Interfacing with additional platform modules o Fabricate hardware o Ground test o Space Assembly demo & performance tests	o Contact heat exchangers between T/C loop segments (i.e between core system & added module) o Fluid disconnects	1 4	o Low thermal resistance, space assembly, light weight designs needed o Large scale, leak-tight disconnects not demonstrated
o Automatic T/C System Control	o Simplify T/C design & operation	X	X	X	X	X	X	B	o Select best concepts o Sensors o Controls o Computer o T/C loop design o Component fab & test o System fab & test o Ground o Space	o Centralized control o Distributed control o Flow bypass vs pump capacity control o Control of both bus & interfacing transport loops	3 3 4 3	o System design performance & controllability not demonstrated oAlgorithms & software not developed

Option Benefits Survey for Thermal Control

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Technology Discipline: THERMAL CONTROL Technology Advancement Goal	Benefits	Applicable to: Manned Platforms			Applicable to: Unmanned Platforms			Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO					
o Constant Temperature Thermal Bus	o Heat absorption temperature independent of location in transport loop o Simplified Control o System easily reconfigured (payload can be located at any berth or cold plate) o Downstream payloads not affected by power fluctuations of upstream payloads	X	X	X	X	X	X	B	o Select best concept(s) o Design, fab & test components o Fabricate T/C system o Test performance o Ground o Space	o Variable conductance heat pipes o Pumped two-phase loop o Hybrid pump assisted heat pipe loop	2 2 2	High Flux pipes not demonstrated Ground test difficult Zero "G" performance not demonstrated Performance on ground and in space not validated
o Life Life Cryogen Refrigeration	o Long term storage of cryogens o Reduce transportation cost of LO_2 & LH_2 o Reduce storage tank size & mass		X			X	X	B	o Improved reliability (life) of existing refrig's o Improve coefficient of performance o Develop advanced LH_2 temperature refrigerator	o Vuillmeir cycle o Reverse Brayton cycle o Axial flow compressor o Variable displacement compressor o Rotary reciprocating compressor o Stirling cycle	4 4 4	o Less than 1 year life currently o Life & performance of full scale systems not demonstrated o Life & Performance not demonstrated

Option Benefits Survey for Thermal Control (Continued)

Technology Discipline: STRUCTURES, MECHANISMS AND MATERIALS Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
STRUCTURAL EFFICIENCY												
o System Considerations	o Reduced cost o Reduced weight o Reduced complexity o Reduced risk	X	X	X	X	X	X	B	Develop efficient structural configuration considering system interactions	o SAMSP o SOC o Other	2	
o Evolutionary Configuration	o Reduced Risk o Adaptability	X	X	X	X	X	X	C	Assess Capability of configuration to accommodate growth	o Docking/Berthing o Construction	2	
o Fail Safe Structures	o Reduced risk o Increased life	X	X	X	X	X	X	D	Failure mode/risk assessment		8	
o Packaging	o Reduced cost o Increased mass/volume	X	X	X	X	X	X	C	Assess Packaging efficiency vs complexity & cost		2	
STRUCTURAL PERFORMANCE												
o System Identification	o Reduced control system complexity o Reduced cost		X	X		X	X	B	Assess measurement techniques and compare with increased control syst. complexity	o Use system identification technique or o Design robust control o Develop adaptive control	3-4	o System ident. techniques reported in the literature.
o Dynamics Prediction Methods	o Reduced risk o Simplification of control algorithms	X	X	X	X	X	X	D	Assess prediction techniques		8	o Well established methodology exists
o Structural Damping	o Disturbance control o Reduced weight o Reduced cost o Reduced control system complexity	X	X	X	X	X	X	B	Assess various damping schemes & compare complexity, cost vs control syst. cost & complex.	o Active damping o Passive damping o Combination	3	o Many current studies ACOSS, VCOSS, PACOSS, etc.
o Structure/Control/Thermal Interaction	o Reduced risk o Increased life	X	X	X	X	X	X	C	Advanced Technology interaction prediction methods		8	o Recent IAC work makes this task easier
o Loads/Environments	o Reduced risk o Increased life	X	X	X	X	X	X	D	Improve environment/loads prediction		8	

Option Benefits Survey for Structures, Mechanisms and Materials

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Technology Discipline: STRUCTURES MECHANISMS & MATERIALS

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned: Adv LEO	Manned: Adv GEO	Unmanned Platforms: Early LEO	Unmanned: Int LEO	Unmanned: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
MECHANISM IMPROVEMENTS												
o Deployment Mechanisms	o Simplicity o Reduced risk o Lower Cost	X	X	X	X	X	X	C	o Design mechanisms to insure deployment in a controlled manner	o Springs o Cables o Other Actuators	some 8 some 4-5	o Solar arrays, appendages, small antennas deployable truss struc. large antennas
o Docking/Berthing Mechanisms	o Reliability o Reduced weight	X	X	X	X	X	X	C	Design reliable docking/berthing mechanisms with low docking loads	o Apollo/Soyuz o Other	8	o Apollo/Soyuz
o Articulating/Rotary Joints	o Reliability o Lower cost	X	X	X	X	X	X	C	Design reliable articulating/rotary joints including utility routing	o Scale up current designs o New designs	8	o Current s/c appendage drives
o Electro-Mechanical Actuators	o Reliability o Reduced risk	X	X	X	X	X	X	C	Design reliable actuators for latching, rotary joints, track switching		8	o Current s/c latching mechanisms
o Tracks & Mobility Systems	o Increased life o Reliability		X	X				B	Design efficient & reliable mobility system		2	o SOC Studies
MATERIALS ADVANCEMENTS												
o Composites (Organic, Metal Matrix)	o Reduced weight o Lower cost o Low CTE	X	X	X	X	X	X	B	Investigate benefits of composite materials	o Metals o Organic matrix matls o Metal matrix matls	8 8 3	o Aluminum, titanium o Glass fibers, graphite fibers
o Composites Lifetime & Properties Prediction	o Reduced weight o Incr. reliability	X	X	X	X	X	X	B	Improve composites lifetime and properties pred. methods			
o Paints & Coatings for Interiors	o Crew comfort o Incr. productivity	X	X	X				D	Develop functional & aesthetically pleasing habitat interiors		8	
o Definition of Contamination Sources	o Reduced risk	X	X	X	X	X	X	B	Improve contamination source prediction methods o Outgassing o Moisture Desorption			o Boeing has a good techniques

Option Benefits Survey for Structures, Mechanisms and Materials (Continued)

Technology Discipline: CREW SYSTEMS - EVA

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
Integration of EMU and MMU								C				
8 psi EVA suit								B				
Standard EVA tools								B				
Improved EVA equipment												
o Comm in helmet								B				
o Headsup display								B				
o Non-venting								B	Regenerable vs non-regenerable heat sinks			
o Regenerable CO_2								B				
o Better battery								B				
o Quick-disconnects								B				
o Test & checkout automation								B				
o Easy-to-clean undergarmet								B				
o Easy-to-clean urine collection devices								B				
o In-suit fecal collection device								B				
o Dextrous glove and/or dextrous glove end effectors								B				
o EMU helmet lights								B				
o EMU Servicing								B	Component vs System level LRU packaging Ground vs space based EMU servicing			
o EVA safety								C	EVA Crew Size: Two vs. Greater than two			
o Larger airlock								B				

Option Benefits Survey for Crew Systems

Technology Discipline: CREW SYSTEMS - ECLSS Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
.Cabin Pressure Design Level		X	X	X					14.7 vs Lower Pressure			
.Upgrading ECLS system and integration of ECLS with other systems.		X	X	X					o Open loop systems o Open air loop with partial or complete water recovery o Integration with EPS o Integration with thermal o Integration with ACS, propulsion o Combinations of above			
Subsystem Architecture		X	X	X					o Centralized o Distributed			
Upgrade and improvements in.												
o Trash management		X	X	X				B				
o Facility Hygiene		X	X	X				A				
o Zero-g clothes washer/dryer		X	X	X				A				
o Zero-g dishwasher		X	X	X				A				
o Zero-g oven		X	X	X				A				
o Zero-g freezer		X	X	X				A				
o Zero-g trash compactor		X	X	X				C				
o Zero-g shower		X	X	X				B				
o Zero-g toilet (easier to use, larger capacity, easy in-space tub exchange)		X	X	X				A				

Option Benefits Survey for Crew Systems (Continued)

Technology Discipline: CREW SYSTEMS - CREW SELECTION & TRAINING Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop the capability to train the large numbers of space station crew members in a more efficient and cost-effective manner		X	X	X				A	Evaluate all current training capability o Multi-shift use o Alternatives Evaluate state-of-the-art training technology o Survey industry Create guidelines for payload training. Space Station simulations and training requirements o Develop plan for developing requirements o On-orbit training Crew Selection Criteria o Technical competence o Adaptive social competence o Methods of evaluation of adaptive competence Crew Training o Technical training o Social sensitivity training o Communication Skills o Group Performance o Simulations of space station group dynamics Learning Technologies o Training techniques o Individually tailored training			

Option Benefits Survey for Crew Systems (Continued)

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Technology Discipline: CREW SYSTEMS - TASK AND PROCEDURE ANALYSIS Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Formulate man-machine function allocation tree procedure		X	X	X	X	X	X	C				
o Formulate quantified risk factors		X	X	X	X	X	X	C				
o Collect, integrate and adopt data on technology characteristics		X	X	X	X	X	X	C				
o Real-time adaptive allocation of functions		X	X	X				A				
o Develop of automated assist to man or develop way man can help machine		X	X	X				A				
o Impact of automation on training and readiness o Onboard simulation and training exercises.		X	X	X				C				
Metabolic Demand Model o Integrate crew size, crew makeup, location, work and activity data with metabolic cost model to produce time-phased/location-specific metabolic costs, O_2 consumption requirements		X	X	X				C				
Workload Prediction o Zero-g time-and-motion study data, methods, and criteria		X	X	X	X	X	X	B				
CAD Crew Simulation Models o EMU-Suited: unrestrained/restrained reach envelopes, translation, with/without MMU, full range of astronaut anthro-prometrics. o IVA: unrestrained/restrained reach envelopes, translation, full-range of astronaut anthro-prometrics.		X	X	X	X	X	X	C				

Option Benefits Survey for Crew Systems (Continued)

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Technology Discipline: CREW SYSTEMS - HABITATION/ACCOMMODATION

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms – Early LEO	Manned Platforms – Adv LEO	Manned Platforms – Adv GEO	Unmanned Platforms – Early LEO	Unmanned Platforms – Int LEO	Unmanned Platforms – Adv LEO	Technology Criticality Category	Specific Trades	Options	Current Technology Readiness Level	Technology Context
o Develop rationale for dedicated vs multifunction work spaces		X	X	X				B	Workstations Functional Areas Modules	o Dedicated o Multipurpose		
o Develop rationale for disposable vs rechargeable articles		X	X	X				B	Clothing Eating utensils			
o Develop more enjoyable exercise equipment and exercise continues		X	X	X				B				

Option Benefits Survey for Crew Systems (Continued)

Technology Discipline: CREW SYSTEMS - WORK STATION

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Crew station design and development techniques		X	X	X				C				
o Natural language interface		X	X	X				A				
o Priority and inhibit logic		X	X	X				C				
o Data entry		X	X	X				C				
o Data storage and retrieval		X	X	X				B				
o Restraint systems		X	X	X				C				
o Optimized and consistent crew interfaces with info management system		X	X	X				C				
o Facility hygiene		X	X	X				B				
o Bulk food systems		X	X	X				B				
o Voice-actuated control of cherry-picker		X	X	X				C				
o Degree of automation												
o Crew station design		X	X	X				D		o Restrain or non-restrained operator? o Dedicated or multi-function workstations? o Redundant or non-redundant workstations? o Specialized or standardized design? o Aggregated or dispersed workstations? o Single or multi-operator workstations? o TV or windows for visual cues?		

Option Benefits Survey for Crew Systems (Continued)

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Technology Discipline	CREW SYSTEM -CREW SAFETY											
Technology Advancement Goal	Benefits	Applicable to: Manned Platforms			Unmanned Platforms			Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO					
o Develop crew rescue options		X	X	X				B		o Multiply redundant system o Escape module o Safe haven		
o Develop satellite safing techniques		X	X	X				C				
o Develop refueling safety techniques		X	X	X				B				
o Develop radiation exposure protection				X				B				

Option Benefits Survey for Crew Systems (Continued)

Technology Discipline / Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop zero-g surgical and dental equipment and procedures		X	X	X				A				
o Develop autonomous medical diagnosis and treatment software		X	X	X				B				

Option Benefits Survey for Crew Systems (Continued)

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Technology Discipline: CREW SYSTEMS - MISSION PLANNING

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms			Applicable to: Unmanned Platforms			Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO					
o Develop autonomous mission planning capability for o satellite servicing o construction o flight support o maintenance for normal and contingency operations		X	X	X				A				

Option Benefits Survey for Crew Systems (Continued)

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Technology Discipline: FLIGHT OPERATIONS - ROBOTICS/SUPERVISORY CONTROL

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop user-oriented language for control of robots			X	X				C				
o Machine control w/time-delay			X	X				C				
o Computer based models and graphics display for o teaching the machine o visual simulation o multi-view points, zoom o updating relative to real world o inactive control			X	X				C				
o Need of understanding/theory on how humans integrate and interpret sensory feedback from several kinds of sensors			X	X				C				
o Level of supervision of machine systems o subsystem level o training requirements o determine required human characteristics			X	X				C				
o Variable/adaptive control access by gr.			X	X				C				
o Variable/adaptive function allocation between humans and machines or robots			X	X				C				
o Training			X	X				C				
o Organizational structure of multi-man crew o optional management structure o auto planning & decision making o interactive display techniques o fail safe or fault tolerant ops strategies			X	X				C				
o System performance and validation o methodology o criteria o test bed validation o progressive validation o flight test scenarios			X	X				C				

Option Benefits Survey for Crew Systems (Continued)

Technology Discipline: FLIGHT OPERATIONS - MAINTENANCE Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop autonomous fault detection and isolation system		X	X	X	X	X	X	C				
o Develop built-in test equipment (BITE)		X	X	X	X	X	X	C				
o Develop autonomous systems status information system for all levels of system readiness from full-up, degraded and emergency modes		X	X	X				B				
o Develop standard connectors (electrical, fluid, gas, data bus, etc.)		X	X	X	X	X	X	B				
o Develop standard LRU's (switches, displays, fans, motors, connectors, etc.)		X	X	X	X	X	X	B				
o Develop leak-proof gas, liquid, and cryogenic subsystem LRU changeout systems.		X	X	X	X	X	X	B				

Option Benefits Survey for Flight Operations

Technology Discipline: FLIGHT OPS - MAINTENANCE Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop standard portable maintenance diagnostic instruments		X	X	X	X	X	X	B				
o Develop standard maintenance tools		X	X	X	X	X	X	C				
o Develop standard machine noise isolation instrument		X	X	X				?				

Option Benefits Survey for Flight Operations (Continued)

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Technology Discipline: FLIGHT OPS - TELEOPERATORS Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop Guidance and Control Technology o Control modes o Control referencing o Control languages o Cooperative control o Guidance sensors o Time delay compensation			X	X				B		Ground control vs space station controlled		
o Develop Sensing Techniques o Visual o Non-visual			X	X				B		o Distributed-coordinated o Scene-enhanced/screen enhanced o Stereoscopic o Frames for control, static/mobile o geometric-type o forces/torques o contact/tacile o hazard detection/ warning o smart sensors o preprocessing/ compressing o formatting o bandwidth		
o Develop Displays o Multifunction o formats o integration o Task-related o Computer graphics o Smart displays o Context-oriented o unburdening, e.g. aural, speech synthesis			X	X				B		o operator controlled o event-driven o reference frame o 3D holography		

Option Benefits Survey for Flight Operations (Continued)

Technology Discipline: FLIGHT OPERATIONS - TELEOPERATORS		Applicable to										
		Manned Platforms			Unmanned Platforms							
Technology Advancement Goal	Benefits	Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
Develop Info Management Technology o Task structure o Strategy/planning o Protocol o Contingencies o Plan modification			X	X				B				
Develop Workload Analysis Technology o Task analysis o Assessment/measures o Management/optimization			X	X				C				
o Develop teleoperator basing options			X	X				B		o Ground based o Space based		
o Develop teleoperator end-effector options			X	X				B		o Dextrous manipulators o Grapple fixture		
o Develop teleoperator manning options			X	X				B		o Manned o Unmanned		
o Develop teleoperator functions			X	X	X			B	Evaluate reboost options Evaluate de-orbit options	o TMS reboost o On-board propulsion o TMS deorbit o On-board propulsion		

Option Benefits Survey for Flight Operations (Continued)

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FORM 2

Technology Discipline: FLIGHT OPERATION - FORMATION FLYING Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop formation flying strategies		X	X					B	o Evaluate alternative concepts (include consideration of the following): o differential nodal regression o frequency of rendezvous opportunities o V for rendezvous o collision avoidance o navigation o comm o guidance o platform mission reqm'ts	o SS and SC in same orbit o close formation o wide coverage constellation o Earth/SS libration point orbiting o Circular orbits o small al:1tude SC fly-by o non- orbits w/ periodic rendezvous o Eliptical orbits o perigee rendezvous o Apogee rendezvous o perigee and apogee rendezvous o line-of-sight		
o Develop orbit trim techniques		X	X	X	X	X	X	B	o Frequency of trim maneuvers o Compatibility of maneuvers w/ propulsion system V o Propulsion system	o On-board o TMS		

Option Benefits Survey for Flight Operations (Continued)

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Technology Discipline: FLIGHT OPERATIONS - FLIGHT SUPPORT

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms			Applicable to: Unmanned Platforms			Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO					
o Develop OTV maintenance concept	o Cost reduction	X	X	X				B	o Maintenance location o Maintenance node when space-based	o Ground-based o Space-based o No maintenance o EVA on dolly o IVA in pressurized hangar o Automated	8 3 8 3 3 1	
LAUNCH, DEPARTURE, APPROACH, RENDEZVOUS, AND CAPTURE												
o Develop operational concepts applicable to all vehicles (orbiter OTV TMS, self-propellent satellites, etc.)		X	X	X				B	o Allocation of functions	o Space station o Vehicle o Ground o Combination of above		
								B	o Allocation of control authority during each phase of mission	o Space station o Vehicle o Ground o Combination of above		
o Develop avoidance zones monitoring and control systems (EMI, plume impingement, collision, etc.)		X	X	X				B				
o Develop launch and capture systems		X	X	X				B	o Alternative launching systems	o Manipulator o RMS o Mobile cherrypicker o Other (HPA) o Fly-away o Catapult system o Tow-away o TMS o other	 8 3 3 1 1 2 	
		X	X	X				B	o Alternative capture systems	o Manipulators o RMS o Mobile CP o Other (HPA) o Fly-in hard docking o Pier o TMS retrieved	 8 3 3 7 1 4	

Option Benefits Survey for Flight Operations (Continued)

Technology Discipline: FLIGHT OPS - S.S. Buildup Ops Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop space station module berthing system		X	X	X				C	o Evaluate alternative concepts	o RMS o HPA o PIDA o MMU o Hard docking o Combinations of the above	8 3 5(?) 8 8 -	
o Develop space station module activation concept		X	X	X				C	o Evaluate alternative concepts	o Remotely controlled o from orbiter o from ground o On-board controlled	 2 2 2	

Option Benefits Survey for Flight Operations (Continued)

FORM 2

Technology Discipline: FLIGHT OPERATIONS - SAT SERVICING - CONSTRUCTION - FLIGHT SUPPORT Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop Fluids Resupply Systems		X	X	X	X	X						
o Delivery								D				
o Storage								D				
o Transfer												
o Connectors								C				
o Manifolds								D				
o Gauging								D				
o Dump								?				
o Contamination Control								?				
o Leak detection								B				
o Leak repair								B				
o Corrosion control								B				
o Develop Cryogenics Resupply Systems												
o Delivery								C	o Alternative delivery systems	o ET scavaging o Dedicated tanker module o On-board storage o Remote storage o Dedicated refueling station o In-hangar		
o Storage								B				
o Transfer												
o Connectors								C				
o Manifolds								D				
o Gauging								B				
o Dump								?				
o Contamination control								?				
o Leak detection								B				
o Leak repair								A				
o Corrosion control								?				

Option Benefits Survey for Flight Operations (Continued)

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FORM 2

Technology Discipline: FLIGHT OPERATIONS - SAT SERVICING - CONSTRUCTION - FLT SUPPORT Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
CREW AIDS												
o Develop a portable, general purpose EVA workstation system		X	X	X	X	X	X	B				
o Develop a portable, general purpose EVA foot restraint		X	X	X	X	X	X	C				
o Develop film and TV		X	X	X	X	X	X	D				
o Develop improved EVA tether systems		X	X	X	X	X	X	C				
o Develop improved edge and corner protectors		X	X	X	X	X	X	D				
o Develop a set of standard, universally used EVA handtools		X	X	X	X	X	X	C				
o Develop an improved EVA tool caddy		X	X	X	X	X	X	C				
o Develop EVA handholds and handrails		X	X	X	X	X	X	D				
o Develop EVA slide wires and clotheslines		X	X	X	X	X	X	D				
o Develop portable and fixed-but pointable EVA lighting systems.		X	X	X	X	X	X	C				

Option Benefits Survey for Flight Operations (Continued)

Technology Discipline	FLIGHT OPERATION - SATELLITE SERVICING, CONSTRUCTION ~~FLIGHT SUPPORT~~	Applicable to										
Technology Advancement Goal	Benefits	Manned Platforms			Unmanned Platforms			Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO					
o Developing holding and positioning equipment	o Mission enabling	X	X	X				B	Payload specific vs multi-function equipment	o Handling & positioning aid (HPA)	2	
										o Module exchange Mechanisms	6	
										o Extract/insert table	2	
										o Pivot/rotate table	2	
										o Attach/remove grapple fixture	2	
										o Grapple Assy standoff	2	
										o Temporary attach device	2	
										o Dolly	2	
										o Elevator	2	
										o Erector set fixture	2	
										o General purpose holding fixture	2	
										o RMS and effector	8	
										o Open cherrypicker	6	
										o Closed cabin cherry- w/ dextrous manip-ulators	2	
										o Dextrous manipulator	6	
	o Mission enabling	X	X	X				B	o Manipulator System o Fixed vs. mobile o Cherrypicker vs. Dextrous Manipulator o Jettison equipment			

Option Benefits Survey for Flight Operations (Continued)

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FORM 2

Technology Discipline: FLIGHT OPERATIONS
- SAT SERVICING
- CONSTRUCTION
- FLIGHT SUPPORT

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop Alignment Inst.			X	X	X	X	X	B				
o Develop Calibration Equipment		X	X	X	X	X	X	B				
o Develop Fault Diagnosis Equip.		X	X	X	X	X	X	B				
o Develop Function Test Equipment		X	X	X	X	X	X	B				
o Develop Bonding Techniques			X	X	?	?	?	C				
o Develop Coating Application Techniques			X	X	?	?	?	B				
o Develop Sun Shield Syst.			X	X				C				
o Develop Wire Splicing Equip.		X	X	X	X	X	X	C				
o Develop Tape Dispensing Equip.			X	X	?	?	?	C				

Option Benefits Survey for Flight Operations (Continued)

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Technology Discipline: FLIGHT OPERATIONS
- SATELLITE SERVICING
- CONSTRUCTION
- ~~FLIGHT SUPPORT~~

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop gas resupply systems		X	X	X	X	X						
o Delivery								C	o Gas delivery nodes	o Modules		
o Storage								D	o Gas storage nodes	o Pumped transfer		
o Transfer *								D	o Gas volume gauging	o Metal tanks		
o Connectors								(?)	o Gas transfer gauging	o Composite mat'l tanks (?) (?)		
o Manifolds									o Gas connectors (generic type)			
o Gauging												
o Dump								C				
o Leak detection								B	o Gas leak detectors			
o Contamination control								?	o Gas contamination control			
o Leak repair								A	o Gas line/gas storage leak repair system			
o Corrosion control								?	o Gas line/gas storage corrosion control			

*Keep generic Connectors

Option Benefits Survey for Flight Operations (Continued)

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FORM 2

Technology Discipline: FLIGHT OPERATIONS - SAT SERVICING - CONSTRUCTION - FLT SUPPORT Technology Advancement Goal	Benefits	Applicable to: Manned Platforms			Unmanned Platforms			Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO					
STORAGE SYSTEMS												
o Develop hangar systems for storing and working on satellites and upper stage vehicles			X					B	o Pressurized vs unpressurized hangars	o New design o ET conversion	3 3	
o Develop storage rack systems for space station equipment, construction and servicing components, and upper stage space parts		X	X	X				B	o Multipurpose storage platforms vs. dedicated pallets	o New designs . Spacelab pallets	3 8	

Option Benefits Survey for Flight Operations (Continued)

FORM 2

FLIGHT OPERATION

Technology Discipline: - SAT SERVICING - CONSTRUCTION - FLT SUPPORT

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
Develop grounding techniques		X	X	X	X	X		C				
Develop optical surface cleaning techniques			X	X	X	X		B				
Develop Umbilical System o gas/fluid/cryo o data o power		X	X	X				B				
Develop self-aligning & adjustment mechanisms		X	X	X	X	X	X	B				
Develop design system			X	X				B				
Develop propulsion system arming/safing system		X	X	X	X	X	X	C				
Develop deployment collision hazard protection system		X	X	X	X	X	X	B				

Option Benefits Survey for Flight Operations (Continued)

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Technology Discipline: GROUND OPERATIONS	Benefits	Applicable to						Technology Criticality Category	Specific Tasks	Options		Current Technology Readiness Level	Technology Context
Technology Advancement Goal		Manned Platforms			Unmanned Platforms								
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO						
Ground Operations include the following functions: o Buildup o Test and checkout o Interface verification o Integration o Servicing o Troubleshooting o Logistics support o Quality control o Safety assurance o Data analysis o Problem reporting and tracking o Configuration management o Manufacturing These functions will be studied in the forthcoming NASA-KSC Space Station Ground Operations Study. Technology identification is one of the study's subtasks, therefore, recommend that we delete these functions from inclusion in this study.													

Option Benefits Survey for Ground Operations

Technology Discipline: DATA MANAGEMENT - SOFTWARE DEVELOPMENT		Applicable to											
		Manned Platforms			Unmanned Platforms								
Technology Advancement Goal	Benefits	Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO	Technology Criticality Category	Specific Tasks	Options		Current Technology Readiness Level	Technology Context
o Develop/evaluate high order language (HOL). Consider current HOLs, HOL under development, and desired capabilities.	o Reduce S/W development costs o Reduce S/W maintenance costs o Reduce schedules for code implementation o Improve reliability of generated code o Simplicity, ease in training o Growth, expandability							A	o Identify candidate HOLs o Determine applicability of candidate HOLs o Perform comparison o Provide recommendation o Consider applicability to real-time systems, command language, training maintainability, testability, structured programming, simplicity, flexibility, availability for microprocessors and distributed architecture concepts, etc. o Include ADA.	o Use available HOLs o Use computer supplier assembler language o Develop new HOL o Participate in working groups, etc. for new HOLs under development		5	New technology on the horizon tied together with microprocessor development as well as supportive S/W as discussed below, could reduce costs and improve the product by leaps and bounds. Difficult for non-S/W personnel to grasp significance. Probably will happen due to push by DoD for ADA. Thus NASA has choice of ADA or traditional methods.
o Develop/evaluate S/W code generation tools including some form of automatically generating code from design and requirements definition.	o All above benefits except applicable to front and of S/W development							B	o Perform as above except for S/W code generation tools instead of HOLs o Consider relationship of these tools to HOL o Include support tools to ADA	o Use manual methods for requirements definition, design o Use current tools if any applicable o Develop new tools o Utilize new tools/techniques under development		5	Would be significant if not for DoD push for ADA and supporting S/W. Traditional methods still evolving

Option Benefits Survey for Data Management

FORM 2

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Technology Discipline: DATA MANAGEMENT -- Software Development

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms			Applicable to: Unmanned Platforms			Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO					
o Develop/evaluate S/W support tools including file editors, file/library/configuration controls, documentation aids, flow and code analyzers/checkers, simulation (instruction and environment).	o Similar to above for HOL.							B	o Perform as above except for S/W support tools instead of HOLs o Consider relationship of these tools to HOL o Include support tools to ADA	o Similar to above: manual, current, develop new tools, cognizant/utilize current developments	5	Would be significant if not for DoD push for ADA and supporting S/W. Traditional methods still evolving.
o Develop/evaluate S/W development management and technical techniques including management controls and reporting and modern programming practices.	o Reduce costs o Reduce schedules o Controls for visibility, reporting, and timely corrective action o Structured programming and other "modern" techniques including standards to follow o Standardized and integrated approach							D	o Define document S/W development methodology (process to be followed) o Define/document "modern" programming practices o Define/document controls, reporting techniques	o Leave to individual S/W contractors/subcontractors o Define common approach for all S/W development regardless of who or where developed	8	Techniques, mechanisms, methods, tools, etc are basically in place if management and engineers would first, lay down the plan, and second, follow the plan.

Option Benefits Survey for Data Management (Continued)

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2 FOLDOUT FRAME

Technology Discipline - DATA MANAGEMENT - COMPUTER HARDWARE & DISTRIBUTED ARCHITECTURE

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Adv LEO	Manned Adv GEO	Unmanned Platforms Early LEO	Unmanned Int LEO	Unmanned Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop/evaluate processors for applicability of microprocessors in a distributed architecture for space applications.	o Lower costs of development and operation o Less weight, volume, power needs o Reliability o Redundancy							B	o Identify candidate micro-processors vs traditional processors o Perform comparison of applicable candidates or select an example for typical application o Describe technology of processor o Discuss characteristics of processor: speed, "word" size, registers, etc. o Applicability of processor to system designs: distributed vs centralized, expandability, redundancy o Availability of HOL and other S/W support o Fault tolerance, BIT	o Traditional processors o Centralized processors with direct data paths to subsystems o Centralized processors with some distribution of "smarts" o Subsystem processors have autonomous capability with some central control	5	Processors & distributed architecture are inter-related since you can't necessarily have distributed architecture without supportive processors and including applicable data bus capability. Parts if not most/all of technology is probably on the horizon if not here. Much depends upon time frame and the requirements demanded from the DM system: speed, fault tolerance. Because of the issue of distributed vs centralized, this would have to remain a relatively high item.
o Develop/evaluate types of data busses applicable to distributed architecture in space environment including fiber optics vs more traditional techniques.	o Lower costs o Less weight o Improved performance o Radiation tolerance							B	o Identify candidate data bus types: fiber optics, coax, twisted pair, etc. o Perform comparison of characteristics o Identify potential "weak links" and study in greater detail. Include fiber optic connectors for connect/disconnect to visiting S/C o Compare radiator tolerance o Describe techniques of expandability/growth	o Fiber optics o More traditional techniques of wax and twisted pairs	5	FO technology is being used for data bussing in various applications. Much of above for processors is true here also. Use and performance of fiber optics in space needs to be checked by the writer. due to the high interest shown in its potential use- and whether it should be used - dictates it being a high item as well as its applicability to distributed architecture and possible high data rates.

Option Benefits Survey for Data Management (Continued)

Technology Discipline: DATA MANAGEMENT - COMPUTER HARDWARE												
Technology Advancement Goal	Benefits	Applicable to: Manned Platforms			Unmanned Platforms			Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO					
o Develop/evaluate memory devices for computer storage which may involve large quantities of data and fast store/retrieve of selected segments of the data.	o Reduce weight, volume, power needs o Reduce costs o Prevent loss of data o Improve flexibility in data storage & retrieval							C	o Identify storage types o Compare performance characteristics (e.g., word/byte format & size, total storage, store/retrieval speed) o Volatility o Expandability/growth	o Tape storage devices (cassettes, cartridges, high density). o Processor memory devices o New technology such as bubble	5	Microprocessors technology with attendant large memories may preclude necessity of large centralized storage requirements. Distributed architecture with the microprocessors contributes to the above. Requirements for data volume generation & storage in an autonomous environment probably the driving factor; ie, how much data is required to be saved or how soon does the data age and can be overwritten. Not as critical as other technology factors.

Option Benefits Survey for Data Management (Continued)

Technology Discipline: DATA MANAGEMENT - CONTROLS & DISPLAYS

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop/evaluate multifunction controls and displays for human space environment	o Reduce weight, volume, power needs o Reduce training o Increase safety							C	o Identify types of functions to be performed o Layout various crew compartments of multi-function displays & keyboards vs older environments o Include high automation via computer driven functions but with crew override capability	o Dedicated displays o Dedicated keys/keyboards o Multi function displays such as CRT's for graphical/pictoral displays as well as digital data o Multi-function keys/keyboards for reconfiguration/back-lighting of functions	5	Technology advancing in this area for aircraft cockpits and C^3I systems including digital computation and displays. Applicable to manned environment only
o Develop/evaluate voice communication techniques for manned compartment as well as other areas such as platform maintenance via EVA	o Reduce training o Increase response time of crew or system action o Ease in performing maintenance or other functions away from manned compartment							C	o Identify types of functions involving voice common. o Identify alternatives to voice communication o Perform comparison of voice communication functions vs other techniques o Determine feasibility/technology of voice communication for above functions o Voice recognition of different crew members	o Keyboard entry o CRT or other display to crew o Independent & self sufficient portable computers for crew support wherever he goes such as for maintenance of other compartments o Terminal plug-in devices with CRT, eye glass, etc readout	5	Technology in this area advancing such as voice boxes for home personal computers. Real need for the capability not defined. Also limited to manned environment.

Option Benefits Survey for Data Management (Continued)

Technology Discipline: DATA MANAGEMENT - CONTROLS & DISPLAYS Technology Advancement Goal	Benefits	Applicable to: Manned Platforms – Early LEO	Manned Platforms – Adv LEO	Manned Platforms – Adv GEO	Unmanned Platforms – Early LEO	Unmanned Platforms – Int LEO	Unmanned Platforms – Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop/evaluate applications of computer generated imagery for utilization in manned space environment.	o Reduce training o Better training o Simulation capability							C	o Identify functions to be performed via CGI o Evalute CGI functions vs traditional/operational methods o Evaluate feasibility & impact of providing CGI	o Utilize TV cameras for visual aids in operational environment if direct visual path not available o Utilize digital and other displays, cautions & warning messages	5	Technology advancing in this area can be used for training (in test/development area) flight crews not only for flight paths but for other operational aspects where direct visual path is not possible. Limited to manned environment. Actual need/requirement not known.

Option Benefits Survey for Data Management (Continued)

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Technology Discipline: COMMUNICATION & TRACKING Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop a lightweight low cost voice/voice bandwidth communication system for intercomm, EVA, proximity and space/ground communications	o Reduced cost o Reduced weight o Improved reliability o Spectrum conservation o Improved personnel safety	X	X	X				Tech. Adv. desired	o Determine multiple access technique	o TDMA o FDMA	4-8	
									o Select digitizing method	o 48 Kbps PCM o 18 Kbps CVSD o 2.4 Kbp LPC	4-8	
									o Select synchronization method	o Synchronous o Asynchronous	4-8 3-4	
									o Select hardware implementation technique	o LSI o VLSI	4-8	
o Develop a space qualified traffic control radar	o Mission enablement o Mission safety o Reduce risk	X	X	X				Tech adv. required	o Select frey band	o X-band o KU band o MM wave	8 4-8 2-3	
									o Select antenna type	o Dish o Phased array	4-8 3-5	
									o Develop architecture	o Multimode o Digital processing o Track while scan o Beam shaping	4-5 4-5 4-5 4-5	
o Develop a high data rate communication link capable of handling up to 4 digitized color TV channels along with other high rate data	o Mission enablement o Reduced cost o Reduced risk	X	X	X				Tech adv required	o Develop a high speed data multiplexing concept	o Emitter coupled Log o LSI o ULSF	1-4	
									o Select TV digitizing technique	o PCM o DPCM o Delta mod o Slow scan	3-8 3-8 3-8 6-8	
									o Develop data compression/ data reduction technique			

Option Benefits Survey for Communication and Tracking

Technology Discipline: COMMUNICATION & TRACKING — Technology Advancement Goal	Benefits	Applicable to: Manned Platforms — Early LEO	Manned Platforms — Adv LEO	Manned Platforms — Adv GEO	Unmanned Platforms — Early LEO	Unmanned Platforms — Int LEO	Unmanned Platforms — Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop reliable command links that are jam & spoof resistant	o Safety o Reduced risk o Improved reliability	X	X	X				Tech adv desired	o Select techniques to minimize message error	o Forward error correction o ARQ o Redundancy		
									o Select technique for false message rejection	o Error detection o Retransmission and verification		
									o Select technique for jamming protection	o Freq. hopping o Direct seq. P/N o Directive antenna o Null steering antennas		
									o Select technique for spoofing protection	o Encryption o Retransmission and validation		

Option Benefits Survey for Communication and Tracking (Continued)

Technology Advancement Goal (Technology Discipline: COMMUNICATION & TRACKING)	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop low probability of intercept data transmission link with A/S and message security	o Reduce risk o Improved reliability	X	X	X				Tech adv desired	o Select low detectability technique	o Frequency hopping	3-4	
										o Direct sequence P/N spreading	3-4	
										o Adaptive transmit power level	3-4	
										o MM-wave CO_2 absorption	2-3	
									o Select message security technique	o Synchronous key stream generator	4-8	
										o Asynchronous page encrypter	2-4	
o Develop communication antenna subsystem that provides spherical coverage	o Mission enablement	X	X	X				Tech adv desired	o Select frequency band	o MF	4-8	
										o HF	4-8	
										o VHF	4-9	
										o MMI-wave	2-4	
										o UHF	4-8	
									o Select antenna type(s)	o Conventional (type depends on frequency)	6-8	
										o Phased array		
										o Conformal phased array	2-4	
									o Select antenna switching technique	o Hot switch	2-4	
										o Cold switch	4-8	
										o No switch	2-4	
o Develop terminal guidance system for automatic docking	o Operational safety o Reduced cost	X	X	X				Tech adv desired	o Select ranging technique	o Laser	4-8	
										o Radar	4-8	
									o Select azimuth/attitude determination technique	o RF interferometer	4-8	
										o Laser retrodirective array	2-4	
									o Select deceleration technique	o Pulsed	4-8	
										o Continuous modulated	2-4	

Option Benefits Survey for Communication and Tracking (Continued)

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Technology Discipline: ELECTRICAL POWER												
Technology Advancement Goal	Benefits	Applicable to: Manned Platforms			Unmanned Platforms			Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO					
o Develop a high power/high voltage power transfer rotary joint to transfer power with high efficiency, low wear, and low noise	o Decrease power system loss o Minimize EMI o Minimize particulate expulsion	X	X	X	X	X	X	B	o Design DC power transfer device for rotary joint o Design AC power transfer device for rotary joint o Analyze performance for power transfer efficiency noise, and contaminants expelled. o Conduct laboratory tests to verify analysis results. o Analyze interaction with plasma environment	o Fabricate and test models o Determine scaling factors o Prepare analytical models for computer programs	3	o Required to transfer the solar array power to the spacecraft. No power transfer device for spacecraft has been made in this size and rating o Efficiency (loss) influences solar array and battery rating o Particulates and EMI impact other systems
o Improve conversion efficiency of solar array by 25%	o Decrease orbit decay due to drag o Decrease orbit makeup fuel quantity o Decrease array stowage volume o Lower array assembly & test cost due to smaller area	X	X	X	X	X	X	B	o Survey in depth the advanced solar cells under development o Test/evaluate sample cells to predict array performance characteristics o Characterize cell performance to develop cell analytical models for computer programs	o Fabricate sample solar array sections to evaluate design parameters to forecast array weight, area, cost	1-2-3	o Solar array size determined by cell efficiency. Array size related to drag and array cost. Higher efficiency cells will reduce array area and stowage volume o Altitude maintenance fuel will be reduced
o Develop efficient, long life, low weight energy storage	o Decrease weight significantly o Decrease life cycle costs o Improve electrical power system and space platform reliability o Integrate the fuel cell system with other spacecraft subsystems to reduce weight and cost o Reduce solar array area o Reduce drag	X	X	X	X	X	X	B B A A/B A	o Determine charging characteristics of Ni-H_2 cells o Evaluate performance and charging characteristics of CPV Ni-H_2 cells o Develop advanced rechargeable lithium batteries o Develop a regenerable fuel cell system (H_2-O_2; H_2-Br_2; H_2-Cl_2) o Analyze flywheel energy storage. Fabricate and test laboratory models to verify parameters	o Fabricate/assemble Ni-H_2 battery to test parameters at battery level o Prepare analytical models for computer programs o Assemble and test lithium cells o Setup and test laboratory models of a regenerable cell system o Set up and test flywheel integrated with attitude control flywheel	3 2 1 2 1	o Energy storage weight is high, significant reduction can be made o Regenerable fuel cell systems show weight and lost savings when integrated with other subsystems o Flywheels can save overall system weight when integrated with attitude control o Flywheel performance more predictable than battery chemistry.

Option Benefits Survey for Electrical Power

Technology Discipline: ELECTRICAL POWER Technology Advancement Goal	Benefits	Applicable to: Manned Platforms			Applicable to: Unmanned Platforms			Technology Criticality Category	Specific Tasks	Option	Current Technology Readiness Level	Technology Context
		Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO					
o Develop high power/high voltage power conditioning components	o Improve power system efficiency. Reduce losses. o Improve power system reliability o Provide S/C equipment now unavailable for high power loads	X	X	X	X	X	X	B	o Develop power conditioning components with high power/ high voltage ratings o Fabricate engineering models o Test/evaluate lab. models o Develop test AC system and DC system components for high power levels o Study/analyze high voltage and plasma interaction	o Prepare analytical models for computer programs o Work with manufacturers to develop high power/ high voltage parts. o Test components in simulated plastma environment	2	o High power level electrical systems require suitable power conditioning components not now available o Voltages must be increased to lower currents o Plasma interaction can be limiting. Not well understood at present.
o Electrical power system automation/autonomy	o Raise reliability of the electrical power system o Minimize operational (manned) hours o Affect spacecraft safety and reliability	X	X	X	X	X	X	B	This task will be carried out in NASA/MSFC contract "Power Subsystem Automation Study" o Coordinate with company awarded contract		2	o Automation/autonomy provides vastly improved and optimized electrical power system o Affects spacecraft operation and design o Lowers life cycle costs significantly.
o Electrical power system cables and connectors	o Reduce weight of cabling for high power electrical power system	X	X	X	X	X	X	C	o Review applicability of fiber optics for power system control and signals o Review flat cable application to power transmission		4	o Wire and cable weight in large spacecraft will be high. Advanced techniques and components can reduce weight.
o Concentrator solar array	o Reduce cost of solar array o Reduce solar cell radiation damage o Permit operating spacecraft in "difficult" orbits (with severe radiation)	X	X	X	X	X	X	B/C	o Test models of advanced concentrator concepts o Determine weight and area for the advanced array designs o Predict performance		1-2-3	o Concentrators offer hardening to space environment - resulting in lower degradation, hence less array area. This affects drag. o Fewer cells lowers array cost

Option Benefits Survey for Electrical Power (Continued)

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FORM 2

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Technology Discipline

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Orbit makeup propulsion selection	o Correct for orbit attitude loss due to aero drag and solar wind. o Facilitate orbit & incliniation change o Accomplish de-orbit	X X X	X X X	X X X	X X X	X X X	X X X	C	o Develop propulsion system that will accomplish the goal and minimize impact on resupply, safety, reliability, and thermal and electrical systems. Must not contaminate sensors and surfaces. Must provide growth potential study feed system dynamics	o Hydrazine o LO_2 - LH_2 o Gaseous O_2-H_2 from EC/LS o Electric propulsion o Resisto-Jet	8 4 4 5 5	Small motors not avail Consume excessive power
o Attitude control system selection	o Accomplish attitude control with no linear acceleration	X	X	X	X	X	X	C	o Develop a system that will accomplish the goal with the features listed above.	o Hydrazine o LO_2-LH_2. o Gaseous O_2-H_2 from EC/LS o Resisto-Jet o Electric Propulsion	8 4 3 3 3	Requires waste gas compression Too much power Pulse mode questionable Low thrust may negate
o De-orbit propulsion kit	o Provide the ability to de-orbit the platform							D	o Select a system that can be delivered to the platform, attached, and fired remotely to accomplish the de-orbit function. Contamination and long-term reliability not an issue.	o Solid fuel o Liquid o Storable o Cryos	8 8 4	Advantages: o Isolates the main propulsion system from this requirement (DV, g's, duration, etc). o Independent of damage failure, etc that may necessitate the de-orbit (self-contained guidance, fuel, power, etc.) o Not an on-board item - therefore, monitoring and periodic check-out not req'd

Option Benefits Survey for Propulsion

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2 FOLDOUT FRAME

Technology Discipline / Technology Advancement Goal	Benefits	Applicable to: Manned Platforms Early LEO	Manned Platforms Adv LEO	Manned Platforms Adv GEO	Unmanned Platforms Early LEO	Unmanned Platforms Int LEO	Unmanned Platforms Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
Cryogen Propellant Transfer & Management	o The ability to provide LO_2/LH_2 for on-board use or STS/OTV refueling	X	X	X	X	X	X	B	o Develop low-g propellant acquisition & transfer techniques o Develop gas-only venting techniques o Develop techniques for gauging amount of propellant in tanks in low-g environment o Develop low heat leak tank supports o Propellant leak protection	<u>Acquisition</u>		
										o Full tank devices	4	
										<u>Venting</u>		
										o Thermo-vent	7	
										<u>Gauging</u>		
										o Mass accounting	4	
										o Radiological	3	
										o RF	3	
										o Acoustic	3	
										<u>Leak Detection</u>		
										o Probe fluids		
										o Induced contamination		
										o Pressure in leakage barrier		

Option Benefits Survey for Propulsion (Continued)

Technology Discipline: GUIDANCE & NAVIGATION TECHNOLOGY TRADES		Applicable to										
		Manned Platforms			Unmanned Platforms							
Technology Advancement Goal	Benefits	Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
Existing technology adequate	o Less risk	X	X	X				D	o Terminal phase rendezvous and docking guidance and control	o Manual (requires crew interface)	8	Guidance & control
Guidance & control algorithms required	o Manned interface not req'd	X	X	X	X	X	X	B	"	o Auto (controlled by SOC computers)	3	
Sensor Development	o Lightens crew workload											
Guidance & control algorithms for multiple close proximity vehicles-traffice management	o Safety for SOC and satellites	X	X	X				C	o Traffice control system	o Manual (SOC operator)	7	Guidance & control
										o Auto (SOC Computer S/W)	3	
	o Lightened workload	X	X	X	X	X	X	B		o Active transponder on target vehicle	3	Nav & tracking
Traffic control radarspherical coverage	o Req't for safety	X X	X X	X X	X X	X X	X X	B B		o Skin-track only	3	
Advanced sensor for determining relative attitudes and displacements	o Req'd for safe docking	X	X	X				B	o Docking Sensor	o Manual (visual vs MMW vs laser, etc)	3	Nav & tracking
		X	X	X	X	X	X	B		o Auto (sensor type-trade) laser, MMW, Ku-band		
		X	X		X	X	X	D	o Orbit determination of SOC			
Advanced IMU's and landmark tracking	o Increased autonomy	X	X	X	(manual)			C (1)		o External-SPS, ground, etc.	8	Inertial navigation
	auto decreases crew workload	X	X	X	X (auto)	X	X	B (1)		o Autonomous (manual vs automatic)	?	
Attitude control of large space structures	Req't	X	X	X	X	X	X	C	o Attitude environment	o Gravity gradient o Inertial o Solar inertial	3	Navigation & control
Relative navigation at large distances	o Accurate knowledge of relative states	X	X		X	X	X	D B	o Relative navigation (formation flying)	o GPS (on free-flyers) vs o Direct comm.	8	Navigation
Demonstrate space-based launch control system	Req't	X	X	X	X	X	X	C	o Launch operations	o Direct data-links o Indirect (thru ground)	3	Guidance, nav, & control
		X	X	X	X	X	X	D				

Option Benefits Survey for Guidance and Navigation

Technology Discipline: ATTITUDE CONTROL		Applicable to										
		Manned Platforms			Unmanned Platforms							
Technology Advancement Goal	Benefits	Early LEO	Adv LEO	Adv GEO	Early LEO	Int LEO	Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop control system that is robust with respect to changing control/structural interaction	o Mission enabling o Safety o Costs thru reduced design analysis & ground testing o Improved performance	X	X		X	X	X	A	o Evaluate system identification schemes o Evaluate self adapting methods o Trade system complexity between two alternates		2 2	
o Develop control techniques for precision instrument pointing	o Mission enabling	X	X		X	X	X	B	o Evaluate distributed control o Evaluate disturbance isolation concepts o Trade distributed, central, and disturbance isolation methods for precision instrument pointing.		2 5	
o Develop methods for damping of structural vibration resulting from disturbance environment or transients such as docking or berthing	o Mission enabling o Reduced weight	X	X		X	X	X	A	o Trade active vs passive damping techniques o Evaluate problems of collocation of sensors & actuators with changing configuration		1	

Option Benefits Survey for Attitude Control

Technology Discipline: ATTITUDE CONTROL

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop techniques required to provide micro g environment	o Scientific mission enabling o Minimum cost	X	X		X	X	X	B	o Trade free flying laboratory versus disturbance isolation versus restricted activities		2	
o Develop guidance, navigation and control system which determines attitude and location autonomously	o Autonomous operation		X			X	X	C	o Evaluate options and hardware for providing autonomous attitude & spacial determination o Determine req'ts on system sofware to optimally combine information from severarl sensor sources.	Trade costs between ground supported & autonomous attitude & navigation	2-7	
o Develop attitude strategy to minimize control propellant penalty within constraints of meeting mission requirements	o Reduced weight o Reduce resupply costs	X	X		X	X	X	C	o Determine best orientation strategy and configuration impacts to minimize control requirements		n/a	
o Develop momentum management methods to minimize momentum storage size.	o Minimize weight o Minimize cost	X	X		X	X	X	C	o Trade alternate methods of momentum desaturation.		2-7	
o Develop control techniques to control docking/berthing transients	o Mission enabling	X	X		X	X	X	C	o Trade alternate techniques to control transients & configuration changes resulting from docking		207	
o Develop control techniques for thruster operation on flexible structure	o Weight reduction o cost reduction	X	X		X	X	X	B	o Evaluate thruster transient control & sensor selection and placement to control flexible structure with on/off thruster transients o Determine stiffness requirements & sensor requirements to minimize structural excitation		2	

Option Benefits Survey for Attitude Control (Continued)

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Technology Discipline: ATTITUDE CONTROL

Technology Advancement Goal	Benefits	Applicable to: Manned Platforms: Early LEO	Manned Platforms: Adv LEO	Manned Platforms: Adv GEO	Unmanned Platforms: Early LEO	Unmanned Platforms: Int LEO	Unmanned Platforms: Adv LEO	Technology Criticality Category	Specific Tasks	Options	Current Technology Readiness Level	Technology Context
o Develop advanced control sensors and actuators for platform control	o Performance improvement o Weight swings o Operations simplification		X	X		X	X	C	o Trade autonomy & accuracy advantages vs risk for advanced sensor systems o Select control hardware to meet mission requirements & evaluate against existing technology. Determine from this analysis hardware technology advancement requirements		2,7,8	
o Develop control sensors and algorithms for rendezvous and docking	o Mission enable	X	X	X		X	X	C	o Define optimum sensors for desired accuracy o Establish processing requirements o Determine technology/hardware requiring further development			

Option Benefits Survey for Attitude Control (Continued)

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4.0 CANDIDATE SPECIFIC BENEFITS VERSUS CRITERIA (FORM 3)

After the first screening of the technology trade candidates, the remaining topics were considered with respect to the specific criteria list of form 3. In this consideration, the evaluators in each remaining discipline applied their background and experience in accessing the candidate against the criteria.

Form 3 sheets were filled out for the following technology disciplines.

Systems Technology
Thermal Control
Crew Systems
Flight Operations
Data Management
Communications and Tracking
Electrical Power
Propulsion and Fluids
Guidance and Control
Attitude Control

After these forms were completed, the evaluators were ready to meet in committee to select the final trade study candidates.

TECHNOLOGY DISCIPLINE	SYSTEMS TECHNOLOGY
TECHNOLOGY ADVANCEMENT GOAL	High Probability of Platform Not Colliding with Another Body with Sufficient Momentum to Cause Damage and Without Prior Warning
SPECIFIC TRADE	Collision Protection and Avoidance

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Increased system complexity.
• SUBSYSTEM IMPACTS	Constrains design of data processing, propulsion, guidance and , EC/LSS and structures.
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	Provide necessary protection to crew and facilities of the space station.
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	Trade between probability of collision including risk of loss and the cost and complexity of automatic protection system.
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	Automatic system for sensing and predicting collisions well in advance of any event so that alarms and evasive maneuvers could be executed. Technology assessment of sensing required - magnitude of data processing required - and maneuvering capability required including structural design to withstand maneuvers.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	SYSTEMS TECHNOLOGY
TECHNOLOGY ADVANCEMENT GOAL	Operation of Essential Services on Platform Without Significant Attention of Crew
SPECIFIC TRADE	Integration of Electrical Power, EC/LSS, and Thermal Control Automation

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Integration and design of central control-sensing and activation of the space station power EC/LSS and thermal control functions.
• SUBSYSTEM IMPACTS	Data processing, power, EC/LSS and thermal control subsystems are constrained.
• PERFORMANCE IMPROVEMENTS • OPERATIONS IMPROVEMENTS	Performance of platform is improved and operations simplified by the crew not having to attend to housekeeping functions. This allows crew to work more on mission functions.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	With variations in services required from power, EC/LSS and thermal automatic regulation and distribution functions would require some advanced sensing and data processing techniques.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	SYSTEMS TECHNOLOGY
TECHNOLOGY ADVANCEMENT GOAL	Assembly and Integration of Add On Components to Space Platforms Without Modification of Existing Units.
SPECIFIC TRADE	

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Facilitates orderly system growth.
• SUBSYSTEM IMPACTS	Constrains design of structures, power, thermal, fluids, EC/LSS and attitude control subsystems.
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	Operations for assembling add on components to existing platforms would be standardized and simplified if common interfaces were used.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	Cost trade between designing for growth from start versus tailoring each add on item to existing configurations or changing existing units for the add on.
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	Commonality from platform to platform would be a by-product of designing interface commonality for growth.
• TECHNOLOGY ADVANCEMENT REQUIRED	The advancement is more in the area of more detailed systems management than in developing new science technology. Determining what interface configurations are best and making sure that the universal designs do not excessively constrain the subsystems.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	SYSTEMS TECHNOLOGY
TECHNOLOGY ADVANCEMENT GOAL	Cost Effective Production of Space Platform Components That Can be Easily Assembled.
SPECIFIC TRADE	Manufacturing Technology, Assembly, Checkout, Test, and Interface Verification Technology.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	Could impact design of structures, fluids, elect. power, attitude control, EC/LSS, communicators, propulsion, data mgt., and thermal subsystem.
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	This technology would be intended to reduce cost and to improve the reliability and performance of the manufactured components of the space platform.
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	Most of this technology is in place - some enhancement might be possible.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	THERMAL CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Automatic T/C System Control
SPECIFIC TRADE	Centralized vs Distributed Control

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Minimum impact of thermal interaction between platform modules.
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	Accurate temperature control +/-3 F.
• OPERATIONS IMPROVEMENTS	System status monitor only, minimal crew support.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	50% reduction in payload thermal design effort.
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Necessary to perform multiple simultaneous operations.
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	THERMAL CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Modular Growth Capability
SPECIFIC TRADE	Contact Heat Exchangers vs Fluid Disconnects

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Add-on modules serviced by centralized T/C system.
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	10-20% mass reduction.
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	Standard thermal interfaces.
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	Standard thermal interfaces between modules.
• SYNERGISM	
• LONG RANGE POTENTIAL	Advanced platform built up out of standard modules.
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	No need for deployment radiators on each module.

TECHNOLOGY DISCIPLINE	THERMAL CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Ten Year Life T/C System
SPECIFIC TRADE	Mechanically Pumped Transport Loop vs Heat Pipe or Pump Assisted Heat Pipe Loop

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	Stable, predictable performance.
• OPERATIONS IMPROVEMENTS	Reduced repair and refurb. time.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	Reduced logistics cost of materials and labor.
• MASS REDUCTION	Reduced spares.
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	Potential of fewer trips.
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	THERMAL CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Ten Year Life T/C System
SPECIFIC TRADE	Maintenance/Repairable System vs Redundant System

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	THERMAL CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Ten Year Life T/C System
SPECIFIC TRADE	Long Life Coatings vs Cleanable/Repairable Coatings

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS • SUBSYSTEM IMPACTS • PERFORMANCE IMPROVEMENTS • OPERATIONS IMPROVEMENTS • SAFETY IMPROVEMENTS • LIFETIME IMPROVEMENTS • MAINTAINABILITY IMPROVEMENT • RELIABILITY IMPROVEMENTS • COST REDUCTION • MASS REDUCTION • RISK REDUCTION • COMMONALITY AMONG PLATFORMS • TECHNOLOGY ADVANCEMENT REQUIRED • SCHEDULE REDUCTION • DESIGN SIMPLIFICATION • SYNERGISM • LONG RANGE POTENTIAL • MISSION ENABLEMENT • SHUTTLE IMPACTS • PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	THERMAL CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Constant Temperature T/C System Flexibility and Growth
SPECIFIC TRADE	Constant Temperature Thermal Bus vs Variable Temperature Bus

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS • SUBSYSTEM IMPACTS	Improved flexibility in configuration larger radiator - minimum contamination standard interfaces, less power.
• PERFORMANCE IMPROVEMENTS	Close control of temperatures over 5% to 100% of rated load.
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	Potentially 10-20% lighter
• RISK REDUCTION	Higher tech risk than variable temp.
• COMMONALITY AMONG PLATFORMS	Greater commonality.
• TECHNOLOGY ADVANCEMENT REQUIRED	High capacity pump assisted heat pipe
• SCHEDULE REDUCTION	Requires more development time.
• DESIGN SIMPLIFICATION	Standard T/C system - payload interface payloads located anywhere in loop.
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Exact temperature control over wide range of duty cycles.
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	CREW SYSTEMS - ECLSS
TECHNOLOGY ADVANCEMENT GOAL	Develop Capabilities to Enable Integration of ECLSS Working Fluids and Gasses With Other Subsystems
SPECIFIC TRADE	Integration With Power, Thermal, ACS, and Propulsion Subsystems

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Fewer number of gasses, fluids, cryo's to build into system
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	May be degradations in some subsystems in lieu of substantial improvements in others
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	Significant storage mass reduction
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	Potentially applicable to unmanned platforms
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	Yes
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	CREW SYSTEMS - MISSION PLANNING
TECHNOLOGY ADVANCEMENT GOAL	Develop Capabilities for Autonomous Mission Planning for Normal and Contingency Operations (SAT Servicing, Construction, FLT Support, Maintenance, Science, etc)
SPECIFIC TRADE	

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	Psycological Advantage of letting crew set own schedules
• OPERATIONS IMPROVEMENTS	Allows real-time adaption
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	Will reduce costs associated with on-ground mission support
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Req'd capability to make S.S. autonomous
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	CREW SYSTEMS - EVA
TECHNOLOGY ADVANCEMENT GOAL	Develop Improved EMU
SPECIFIC TRADE	8 PSI EMU Non-Venting Radiator CO_2 Removal Regeneration Other Improvements

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	Easier to don, use, doff, and recondition
• OPERATIONS IMPROVEMENTS	No prebreath, faster reconditioning
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	Resupply cost reduced
• MASS REDUCTION	Water and LIOH Cartridge logistics and storage burden removed
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Improvements req'd to make EVA routine and efficient
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	FLIGHT OPERATIONS - GENERAL PURPOSE SUPPORT EQUIPMENT
TECHNOLOGY ADVANCEMENT GOAL	Develop improved performance manipulator system for the space station
SPECIFIC TRADE	Fixed vs mobile Cherrypicker vs. Dextrous Manipulator vs. RMS end-effective IVA vs EVA Operated

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS*	>>100% improvement over RMS (strength, speed, dexterity, etc.)
• OPERATIONS IMPROVEMENTS*	Must be much more productive in order to service all mission needs
• SAFETY IMPROVEMENTS	Must be man-rated
• LIFETIME IMPROVEMENTS	10 year life w/maintenance
• MAINTAINABILITY IMPROVEMENT	Must be space-maintainable
• RELIABILITY IMPROVEMENTS	Requires >95% availability
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Must have in order to perform missions
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

*Must be capable of launching and retrieving vehicles/satellites as well as moving articles around the S.S.

TECHNOLOGY DISCIPLINE	FLIGHT OPERATIONS - SATELLITE SERVICING CONSTRUCTION, FLIGHT SUPPORT, MAINTENANCE
TECHNOLOGY ADVANCEMENT GOAL	Develop Capability for In-space Gas, Liquid, and Cryogenic resupply and Leak-proof Changeout of Subsystems LRU's.
SPECIFIC TRADE	Delivery Modes Storage Modes Transfer Modes Leak Detection Leak Repair Leak-Proof LRU Changeout Guaging

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Reduced on-board storage
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	Must be simple, fast
• OPERATIONS IMPROVEMENTS	Must be fail-safe
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	Req'd capabilities to attain 10-25 yr lifetime for S.S.
• MAINTAINABILITY IMPROVEMENT	Must be maintainable in-space
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	Applicable to unmanned platform as well as S.S.
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	Interrelated with ECLS, Thermal, propulsion, mission, OPS
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Required to make S.S. autonomous
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

OPERATIONS AND CREW SYSTEMS TECHNOLOGY ITEMS SCREENING

ITEMS DELETED AND RATIONALE

ITEM DELETED	RATIONALE
Develop umbilical system for connecting space station fluids, gases, cryos, power, and data bus to vehicles and spacecraft.	This is primarily a design problem. The gas, fluid, and cryo connector technology is addressed in one of the technology items kept in this sort.
Develop portable, general-purpose EVA workstation.	Could use shuttle hardware but will incur a performance degradation.
Develop space-based OTV.	Not essential for early space station.
Develop standard connectors.	Highly desirable for maintainability and operation but could reluctantly use off-the-shelf hardware.
Develop natural language computer man-machine interface.	Long-range goal but could use current technology for early space station.
Develop improved crew training capabilities.	Not essential for early space station with small crews. Will be very important as crew size and operational demands increase.
Develop zero-g surgical and dental equipment and techniques.	Not essential for early space station but will be req'd as station becomes larger.
Develop improved zero-g toilet.	Shuttle toilet could be used with some human factors modifications.

TECHNOLOGY DISCIPLINE	DATA MANAGEMENT
TECHNOLOGY ADVANCEMENT GOAL	Develop/evaluate Multifunction Controls and Displays for Human Space Environment.
SPECIFIC TRADE	Evaluate Multifunction Controls and Displays vs Dedicated Orientation.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	X
• PERFORMANCE IMPROVEMENTS	X
• OPERATIONS IMPROVEMENTS	X
• SAFETY IMPROVEMENTS	X
• LIFETIME IMPROVEMENTS	X
• MAINTAINABILITY IMPROVEMENT	X
• RELIABILITY IMPROVEMENTS	X
• COST REDUCTION	X
• MASS REDUCTION	X
• RISK REDUCTION	X
• COMMONALITY AMONG PLATFORMS	Applicable to manned platforms.
• TECHNOLOGY ADVANCEMENT REQUIRED	X
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	DATA MANAGEMENT
TECHNOLOGY ADVANCEMENT GOAL	Develop/Evaluate Voice Communication Techniques for Manned Compartment as Well as Other Areas Such as Platform Maintenance via EVA
SPECIFIC TRADE	Evaluate Voice Activation/Response Techniques vs Conventional Controls/Displays.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	X
• PERFORMANCE IMPROVEMENTS	Easier manned interface.
• OPERATIONS IMPROVEMENTS	Easier manned interface
• SAFETY IMPROVEMENTS	Warning Clarity, quicker response.
• LIFETIME IMPROVEMENTS	X
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	Reduce risks in operation with manned interface.
• COMMONALITY AMONG PLATFORMS	Applicable to manned platforms.
• TECHNOLOGY ADVANCEMENT REQUIRED	Need further enhancements.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	DATA MANAGEMENT
TECHNOLOGY ADVANCEMENT GOAL	Develop/evaluate Processors for Applicability of Microprocessors in a Distributed Architecture for Space Applications.
SPECIFIC TRADE	Evaluate Advanced Microprocessors (eg, 32 bit) in a Distributed Architecture

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	Processor part of subsystem
• PERFORMANCE IMPROVEMENTS	X
• OPERATIONS IMPROVEMENTS	Subsystem oriented.
• SAFETY IMPROVEMENTS	Due to maintainability, reliability
• LIFETIME IMPROVEMENTS	X
• MAINTAINABILITY IMPROVEMENT	X
• RELIABILITY IMPROVEMENTS	X
• COST REDUCTION	X
• MASS REDUCTION	Chip technology.
• RISK REDUCTION	X
• COMMONALITY AMONG PLATFORMS	Use same processors for all.
• TECHNOLOGY ADVANCEMENT REQUIRED	Processors under development, multi-processing environment required.
• SCHEDULE REDUCTION	X
• DESIGN SIMPLIFICATION	Eliminate complex central system.
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	DATA MANAGEMENT
TECHNOLOGY ADVANCEMENT GOAL	Develop/Evaluate Types of Data Busses Applicable to Distributed Architecture Including Fiber Optics.
SPECIFIC TRADE	Evaluate Data Busses Applicable to Platform Environment; Specifically Include Fiber Optics

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Platform data communication.
• SUBSYSTEM IMPACTS	X
• PERFORMANCE IMPROVEMENTS	X
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	Due to maintainability, reliability.
• LIFETIME IMPROVEMENTS	X
• MAINTAINABILITY IMPROVEMENT	X
• RELIABILITY IMPROVEMENTS	X
• COST REDUCTION	X
• MASS REDUCTION	Fiber optics; less weight, volume
• RISK REDUCTION	X
• COMMONALITY AMONG PLATFORMS	Use same data bus for all, voice comm for manned platform may be a factor.
• TECHNOLOGY ADVANCEMENT REQUIRED	Application to platform creates environment different from ground; eg, radiation.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	X
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	DATA MANAGEMENT
TECHNOLOGY ADVANCEMENT GOAL	Develop/Evaluate Software Cocegeneration Tools Including Some Form of Automatically Generating Code From Design and Requirements Definitions.
SPECIFIC TRADE	Evaluate Requirements Definition and Design Aid Tools to Determine Applicability of Assisting in Generation of Source Code; Include Correlation to HOL (eg, ADA)

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	Reduce Chance of code errors.
• LIFETIME IMPROVEMENTS	Easier creation of code from requirements.
• MAINTAINABILITY IMPROVEMENT	Easier to chance code from changer in requirements.
• RELIABILITY IMPROVEMENTS	Reduction in code errors.
• COST REDUCTION	Reduce manpower to generate code.
• MASS REDUCTION	
• RISK REDUCTION	Reduce chance of code errors.
• COMMONALITY AMONG PLATFORMS	Same S/W development tools for all.
• TECHNOLOGY ADVANCEMENT REQUIRED	Some tools available, enhancements needed.
• SCHEDULE REDUCTION	Easier to produce code directly.
• DESIGN SIMPLIFICATION	Easier to produce code directly.
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	DATA MANAGEMENT
TECHNOLOGY ADVANCEMENT GOAL	Develop/Evaluate software Support Tools Including File Editors, File/Library/Configuration Controls, Documentation Aids, etc.
SPECIFIC TRADE	Evaluate HOL (eg, ADA) and other S/W Development Support Tools for Increasing Programmer productivity and Software Reliability

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	Via better support tools, less errors.
• MAINTAINABILITY IMPROVEMENT	Via better support tools, less errors.
• RELIABILITY IMPROVEMENTS	Via better support tools, less errors.
• COST REDUCTION	Via increased productivity and reliability.
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	Via use of same support tools for all.
• TECHNOLOGY ADVANCEMENT REQUIRED	Tools available, enhancements required.
• SCHEDULE REDUCTION	Via better support tools, less errors.
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	DATA MANAGEMENT
TECHNOLOGY ADVANCEMENT GOAL	Develop/Evaluate High Order Language (HOL)
SPECIFIC TRADE	Evaluate ADA* as a HOL for Space Application vs Current Language Usage.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	Possible via reliability, maintainability.
• LIFETIME IMPROVEMENTS	Via use of HOL designed for future.
• MAINTAINABILITY IMPROVEMENT	Via use of HOL.
• RELIABILITY IMPROVEMENTS	Via use of HOL.
• COST REDUCTION	Via use of HOL.
• MASS REDUCTION	
• RISK REDUCTION	Via use of HOL.
• COMMONALITY AMONG PLATFORMS	Via use of same HOL for all.
• TECHNOLOGY ADVANCEMENT REQUIRED	Advancement underway for DOD, application to space unknown.
• SCHEDULE REDUCTION	Via use of HOL.
• DESIGN SIMPLIFICATION	Via use of HOL.
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

*ADA is new HOL specifically directed by DOD to be developed for common use by all military branches for military applications to avoid proliferation of various languages, utilize best features of all, avoid pitfalls of others, and add desired/required features.

TECHNOLOGY DISCIPLINE	COMMUNICATION AND TRACKING
TECHNOLOGY ADVANCEMENT GOAL	Develop a Terminal Guidance System for Automatic Space Docking
SPECIFIC TRADE	Radio Frequency vs Optical/Laser

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	Minimizes Pilot/astronaut work load.
• SAFETY IMPROVEMENTS	Minimizes probability of docking damage.
• LIFETIME IMPROVEMENTS	Readily accomodates increased docking traffic/frequency.
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	Reduces amount of docking training/practice required.
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Required for Unmanned spacecraft docking.
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	COMMUNICATION AND TRACKING
TECHNOLOGY ADVANCEMENT GOAL	Develop a Lightweight-Low Cost Voice/Voice Bandwidth Communication System for Intercom, EVA, Proximity, and Space/Ground Communications.
SPECIFIC TRADE	Digital Voice - Time Division Multiplex vs Analog Voice - Frequency Division Multiplex

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	Digitized voice and time division multiplexing simplifies voice distribution, voice conferencing and voice freq. data distribution.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	Increased hardware commonality.
• RELIABILITY IMPROVEMENTS	Digital circuits replace analog circuits.
• COST REDUCTION	Hardware commonality reduces unit cost and spares provisioning quantities.
• MASS REDUCTION	LSE/VLSI implementation reduces mass 75% fewer interconnecting cables required.
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	Standard modules common to all platforms.
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	Digitized voice circuits simplify the transmission of data (eg: biomedical) over voice circuits.
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	COMMUNICATION AND TRACKING
TECHNOLOGY ADVANCEMENT GOAL	Develop a High Data Rate Communication Link Capable of Handling Up to 4 Digitized Color TV Channels Along With Other High Rate Data.
SPECIFIC TRADE	Single High Rate Data Link vs Separate Analog TV Links and Data Link(s)

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	Digital vs Analog Circuits.
• COST REDUCTION	
• MASS REDUCTION	Provides 75% mass reduction compared with separate analog TV channels.
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	Requires development of high speed, modulator, multiplexers, and A/D & D/A converters.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Provides Hi Res. dictorial data for troubleshooting. Enable transmission or Hi Res video mission data.
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	COMMUNICATION AND TRACKING
TECHNOLOGY ADVANCEMENT GOAL	Develop a Space Qualified Traffic Control Radar
SPECIFIC TRADE	Multi Mode, Phased Array, Digital Processing vs Sēparate Search and Tracking Radars With Mechanically Scanned Antennas and Analog Processing

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	Location & Status of Relevant Space Objects Provided.
• SAFETY IMPROVEMENTS	Conflict/collusion warning for spacecraft & debris provided.
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT • RELIABILITY IMPROVEMENTS	Maximum use of digital circuitry increases maintainability & reliability.
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Require to detect & track incomming & outgoing spacecraft. Detect space debris, and provide conflict/collusion alarm.
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	ELECTRICAL POWER
TECHNOLOGY ADVANCEMENT GOAL	Develop Automated Electrical Power System to Improve Reliability By An Order of Magnitude and Reduce Operating Cost (Manpower) By An Order of Magnitude.
SPECIFIC TRADE	Comparison of Degree of Automation vs Weight, Man-Machine Sharing of Automation, Improvement in Reliability and Life vs Degree of Automation.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Contribution to platform automation.
• SUBSYSTEM IMPACTS	Improvement in life and reliability of EPS.
• PERFORMANCE IMPROVEMENTS	Improved Reaction to malfunctions.
• OPERATIONS IMPROVEMENTS	Permits planning of difficult operations without dependence on man.
• SAFETY IMPROVEMENTS	Promotes system safety-can react instantly to problems
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	Improves life by optimizing performance under all conditions.
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	Minimizes maintenance requirements.
• MASS REDUCTION	Increases reliability
• RISK REDUCTION	Reduces risk because of constant monitoring and control.
• COMMONALITY AMONG PLATFORMS	Applicable to all platforms.
• TECHNOLOGY ADVANCEMENT REQUIRED	Preliminary automation is S-O-A. Requires advanced sensors and latest microprocessors.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	Will affect thermal control.
• MISSION ENABLEMENT	Back up to on board computer control functions.
• SHUTTLE IMPACTS	Required for automation of space platform and station.
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	ELECTRICAL POWER
TECHNOLOGY ADVANCEMENT GOAL	Develop an Advanced Energy Storage System of Low Mass - High Energy Density, to Replace NiCd Batteries.
SPECIFIC TRADE	Compare Ni Cd Batteries With Regenerable Fuel Cells, $Ni-H_2$ Batteries, and Flywheels at a Space Station Level to Determine Integration Effect.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Energy storage will constitute significant mass.
• SUBSYSTEM IMPACTS	Minimization of energy storage mass.
• PERFORMANCE IMPROVEMENTS	Improve reliability of E.P.S.
• OPERATIONS IMPROVEMENTS	Support steady state and transient loads with minimum mass.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	Increase energy storage life with minimum mass.
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	Minimize life cycle cost.
• MASS REDUCTION	Minimize system mass by integration with other subsystems.
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	Can be used with all platform concepts.
• TECHNOLOGY ADVANCEMENT REQUIRED	Regenerable fuel cell system and flywheel energy storage are developmental. $Ni-H_2$ cells are developmental for LEO applic.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	Minimize solar array area (drag)
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	Efficient energy storage required for space platforms.
• PACKAGING IMPACTS	Batteries or fuel cells will affect packaging volume.

NOTE: Utilize results from studies of:
Regenerable Fuel Cells.
Flywheel Energy Storage.

TECHNOLOGY DISCIPLINE	ELECTRICAL POWER
TECHNOLOGY ADVANCEMENT GOAL	Develop High-Power/High-Voltage Power Conditioning For Space Platforms & Space Stations.
SPECIFIC TRADE	Compare Multiple Units of Lower Rating With Large Single Units to Be Developed. Compare Cost, Weight, Reliability, Efficiency, EMI.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Higher efficiency will reduce solar array area and overall system weight.
• SUBSYSTEM IMPACTS	Simplification of E.P.S.
• PERFORMANCE IMPROVEMENTS	Higher efficiency and Reliability.
• OPERATIONS IMPROVEMENTS	Higher energy density will reduce E.P.S. volume.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	Higher reliability with fewer components in parallel.
• COST REDUCTION	
• MASS REDUCTION	Lower mass from higher efficiency and higher energy density.
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	Small platforms can use S-O-A components. Large platforms will require advanced components.
• TECHNOLOGY ADVANCEMENT REQUIRED	Power conditioning equipment for high power in large units are not available. Advanced solid state devices to be developed.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	Higher efficiency components will simplify thermal control and reduce E.P.S. mass and array area (drag)
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	Higher efficiency components will reduce packaging volume.

TECHNOLOGY DISCIPLINE	ELECTRICAL POWER
TECHNOLOGY ADVANCEMENT GOAL	Provide/Develop a High-Power Rotary Joint With High Efficiency, Low Noise, Low Wear and Debris.
SPECIFIC TRADE	Brush/Slipring Concept vs Rotary Transformer Concept.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Enable rotation while transferring power to spacecraft.
• SUBSYSTEM IMPACTS	Minimize loss and system weight.
• PERFORMANCE IMPROVEMENTS	Provide low EMI power transfer. Minimize contamination debris.
• OPERATIONS IMPROVEMENTS	Non-restrictive motion of solar array.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	Low wear and little contamination debris.
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	High efficiency will decrease loss and system mass.
• RISK REDUCTION	This size of power transfer has not been accomplished to date.
• COMMONALITY AMONG PLATFORMS	Can be used for any platform concept.
• TECHNOLOGY ADVANCEMENT REQUIRED	The size and power level will be greater than any to date. Materials rating will be limiting. Scaling factor unknown. Rotary transformer is still developmental. Interaction with space plasma will be a problem. Thermal control will also be a problem.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	A power transfer joint is necessary to operate the spacecraft as planned. (Enabling).
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	Concept will affect platform packaging configurations.

TECHNOLOGY DISCIPLINE	ELECTRICAL POWER
TECHNOLOGY ADVANCEMENT GOAL	Develop a Solar Array Concentrator to Lower Array Cost By 25-50% and Provide Hardening For Military Applications.
SPECIFIC TRADE	Compare Several Concentrator Concepts and Planar Arrays for Cost, Weight, and Hardening.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS • SUBSYSTEM IMPACTS • PERFORMANCE IMPROVEMENTS • OPERATIONS IMPROVEMENTS • SAFETY IMPROVEMENTS • LIFETIME IMPROVEMENTS • MAINTAINABILITY IMPROVEMENT • RELIABILITY IMPROVEMENTS • COST REDUCTION • MASS REDUCTION • RISK REDUCTION • COMMONALITY AMONG PLATFORMS • TECHNOLOGY ADVANCEMENT REQUIRED • SCHEDULE REDUCTION • DESIGN SIMPLIFICATION • SYNERGISM • LONG RANGE POTENTIAL • MISSION ENABLEMENT • SHUTTLE IMPACTS • PACKAGING IMPACTS	Array Concept will affect configuration, thermal control, area, mass, cost. Array concept will determine power system cost, array area, array mass, volume (stowing). Concentrator will Have Lower Degradation to Manmade and Natural Environment. Concentrator Can resist degradation and improve reliability. Cost reduction will result from concentrator array using fewer solar cells. Array concept can be used with any platform or station concept. Concentrator array technology is developmental. Some concepts incorporate advanced heat pipes. Solar array concept will affect attitude control system for array pointing. Stiffness of array will change panel frequency. Concentrator array will provide hardening for military missions. (Enabling). Concept selected will determine array packaging and stowage.

TECHNOLOGY DISCIPLINE	PROPULSION AND FLUIDS
TECHNOLOGY ADVANCEMENT GOAL	Improved performance and reliability. Reduced system impact. Growth potential
SPECIFIC TRADE	Orbit Makeup Propulsion Selection

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Use of propellants on-board for other reasons (OTV, EC/LS).
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	Increased Isp, development of small LH_2/LO_2 motors.
• OPERATIONS IMPROVEMENTS	Commonality of propellants.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	Small, reliable LH_2/LO_2 motor development.
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	Small LH_2/LO_2 motor.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	Commonality of propellant tankage and plumbing.
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	Propellant commonality (resupply).
• PACKAGING IMPACTS	Propellant commonality (resupply).

TECHNOLOGY DISCIPLINE	PROPULSION AND FLUIDS
TECHNOLOGY ADVANCEMENT GOAL	Develop techniques for low-g acquisition and transfer. Improve long-term storage abilities.
SPECIFIC TRADE	Cryogen Propellant Transfer and Management

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Low-g acquisition negates need to accelerate to settle propellants.
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	Cryos offer improved performance.
• OPERATIONS IMPROVEMENTS	Facilitates loading and off-loading of propellants.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	Low-g acquisition with 95% tank emptying capability.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	Facilitates use of cryos for all propulsion systems.
• SYNERGISM	
• LONG RANGE POTENTIAL	Development of techniques for acquisition and trasnfer of cryogene at low-g levels.
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	Off-load from Orbiter (resupply).
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	PROPULSION AND FLUIDS
TECHNOLOGY ADVANCEMENT GOAL	Improved performance. Propellant commonality.
SPECIFIC TRADE	Attitude Control System Selection

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Use of propellant on-board for makeup propulsion, OTV, EC/LS.
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	Improved with LH_2/LO_2 system.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	Small LO_2/LH_2 motor.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	Commonality of propellant tankage and plumbing.
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	Propellant commonality (resupply)
• PACKAGING IMPACTS	Propellant commonality (resupply)

TECHNOLOGY DISCIPLINE	GUIDANCE & CONTROL - APPROACH AND DOCKING
TECHNOLOGY ADVANCEMENT GOAL	Develop Automated Approach and Docking Algorithms.
SPECIFIC TRADE	Entirely Automated vs Manual Interface

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Requires dedicated computer time and memory.
• SUBSYSTEM IMPACTS	Requires sensor development.
• PERFORMANCE IMPROVEMENTS	Reduces approach fuel usage.
• OPERATIONS IMPROVEMENTS	Lessens crew workload-may be requirement during high traffic loads.
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	Fuel usage reduction on active vehicles.
• RISK REDUCTION	Decreases chance of "pilot error", reduces collision probability.
• COMMONALITY AMONG PLATFORMS	Standard system for all vehicles.
• TECHNOLOGY ADVANCEMENT REQUIRED	Develop guidance algorithms-applicable to any sensor-compatible space system.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	Numerous DOD & commercial applications.
• MISSION ENABLEMENT	Enables docking between unmanned systems required for high traffic loads.
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	TRACKING & NAVIGATION - APPROACH/DOCKING SENSOR
TECHNOLOGY ADVANCEMENT GOAL	Sensor for Docking - Must Include Relative Attitude (3 Axis) and Relative Displacements (3 Axis)
SPECIFIC TRADE	Sensor Type (Visual, Laser, AMW, etc).

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	Requires sensor system for SOC and chaser vehicles.
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	Requirement for docking w/unmanned vehicles.
• SAFETY IMPROVEMENTS	Improved safety for docking manned vehicles.
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	Relative attitude/displacement sensors of very high accuracy.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Must be able to dock OTV's & other unmanned/manned vehicles.
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	GUIDANCE & NAVIGATION - CLOSE-IN TRAFFIC CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Advanced Relative Navigation Techniques & Guidance Algorithms (Multiple Vehicles)
SPECIFIC TRADE	1. Automative vs Manual Interface. 2. Sensor Study.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Dedicated Computer Time/Memory.
• SUBSYSTEM IMPACTS	Requires spherical sensor coverage.
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	Enables constant monitoring & control without crew interface.
• SAFETY IMPROVEMENTS	Prevents accidental impact or interference between vehicles.
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	Reduces risk of vehicle collisions.
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	More comprehensive & flexible algorithms spherical antenna coverage.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Allows multiple vehicles to operate in close proximity.
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	GUIDANCE, TRACKING, NAVIGATION & CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Space-based Launch Control System
SPECIFIC TRADE	1. Degree of Automation. 4. Autonomy vs Ground Support. 2. Required Sensors. 3. Required Software.

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Mass Storage and core memory.
• SUBSYSTEM IMPACTS	Requires comm/tracking sensors. Interface with TDRSS.
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	Makes SOC more autonomous.
• SAFETY IMPROVEMENTS	Quicker response, better reliability than through ground.
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	Entire system maintained onboard.
• RELIABILITY IMPROVEMENTS	Fewer data/comm links with ground.
• COST REDUCTION	Reduces ground support requirement.
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	Space based sensors, modified algorithms.
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	Able to launch with minimum ground support/ requirements.
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	ATTITUDE CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Develop Control System That is Robust With Respect to Changing Control/Structural Interaction
SPECIFIC TRADE	Evaluate Adoptive Control & System Identification Schemes and Determine Best Alternatives

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	Subsystem has less impact on restrictions to configuration or structural stiffness
• PERFORMANCE IMPROVEMENTS	Better control performance and greater stability margins.
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	Make subsystem more adaptable to component failures and changes.
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	Reduced mass from lower structural stiffness requirements.
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	ATTITUDE CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Develop Techniques for Damping Structural Vibrations Resulting From Onboard Disturbances and Docking/Berthing Transients
SPECIFIC TRADE	Trade Active vs Passive Damping Techniques Evaluate Problems in Sensor/Effector Locations With Changing Configuration

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Reduce Transients throughout system.
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	Improve comfort to crew
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	ATTITUDE CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Develop Control Techniques for Precision Instrument Pointing.
SPECIFIC TRADE	Trade Distributed and Centralized Control and Disturbance Isolation Techniques to Provide Precision Instrument Pointing

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS • SUBSYSTEM IMPACTS • PERFORMANCE IMPROVEMENTS • OPERATIONS IMPROVEMENTS • SAFETY IMPROVEMENTS • LIFETIME IMPROVEMENTS • MAINTAINABILITY IMPROVEMENT • RELIABILITY IMPROVEMENTS • COST REDUCTION • MASS REDUCTION • RISK REDUCTION • COMMONALITY AMONG PLATFORMS • TECHNOLOGY ADVANCEMENT REQUIRED • SCHEDULE REDUCTION • DESIGN SIMPLIFICATION • SYNERGISM • LONG RANGE POTENTIAL • MISSION ENABLEMENT • SHUTTLE IMPACTS • PACKAGING IMPACTS	Provide capability to point instruments for scientific study

TECHNOLOGY DISCIPLINE	ATTITUDE CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Develop Techniques Required to Provide Micro g Environment
SPECIFIC TRADE	Trade Free Flying Lab vs Disturbance Isolation Techniques

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS • SUBSYSTEM IMPACTS • PERFORMANCE IMPROVEMENTS • OPERATIONS IMPROVEMENTS • SAFETY IMPROVEMENTS • LIFETIME IMPROVEMENTS • MAINTAINABILITY IMPROVEMENT • RELIABILITY IMPROVEMENTS • COST REDUCTION • MASS REDUCTION • RISK REDUCTION • COMMONALITY AMONG PLATFORMS • TECHNOLOGY ADVANCEMENT REQUIRED • SCHEDULE REDUCTION • DESIGN SIMPLIFICATION • SYNERGISM • LONG RANGE POTENTIAL • MISSION ENABLEMENT • SHUTTLE IMPACTS • PACKAGING IMPACTS	Provide required environment for scientific missions.

TECHNOLOGY DISCIPLINE	ATTITUDE CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Develop Control Techniques for Thruster Operation on a Flexible Structure
SPECIFIC TRADE	Determine Sensor/Thruster Location. Determine Stiffness Requirements. Determine Trade Between Stiffness Thrust Level and Control Duty Cycle

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	Maximize common control & station keeping propellent commonality
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	Reduce resupply costs.
• MASS REDUCTION	Reduction through lower stiffness and reduced control propellant
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

TECHNOLOGY DISCIPLINE	ATTITUDE CONTROL
TECHNOLOGY ADVANCEMENT GOAL	Develop Control Techniques to Control Docking/Berthing Transients
SPECIFIC TRADE	Trade Best Techniques for Controlling Docking/Berthing Transients. Evaluate Local vs System Transient Reductions

CRITERIA	ESTIMATED BENEFIT
• SYSTEM IMPACTS	
• SUBSYSTEM IMPACTS	
• PERFORMANCE IMPROVEMENTS	Reduce control complexity if done locally.
• OPERATIONS IMPROVEMENTS	
• SAFETY IMPROVEMENTS	Anomoly handling during docking/berthing.
• LIFETIME IMPROVEMENTS	
• MAINTAINABILITY IMPROVEMENT	
• RELIABILITY IMPROVEMENTS	
• COST REDUCTION	
• MASS REDUCTION	
• RISK REDUCTION	
• COMMONALITY AMONG PLATFORMS	Docking/berthing port design for all connections.
• TECHNOLOGY ADVANCEMENT REQUIRED	
• SCHEDULE REDUCTION	
• DESIGN SIMPLIFICATION	
• SYNERGISM	
• LONG RANGE POTENTIAL	
• MISSION ENABLEMENT	
• SHUTTLE IMPACTS	
• PACKAGING IMPACTS	

Mechanisms/Control Interface

5.0 TRADE STUDY OPTION SURVEY (FORM 3A)

The Form 3A sheets summarize the results of the trade studies conducted in four subject areas:

Data Management - Architecture
Data Management - Data Bus
Long Lifeline Thermal Management
Integration of Automated Housekeeping

In filling out the sheets the evaluators completed comparisons between the options considered with respect to performance pointers, safety impacts, lifetime impacts, maintainability impacts, cost and other factors. These sheets give an overview of the trade study results.

TECHNOLOGY DISCIPLINE: DATA MANAGEMENT ARCHITECTURE

TECHNOLOGY ADVANCEMENT GOAL: HIGH PERFORMANCE, FAULT TOLERANT & MODULAR SYSTEM

SPECIFIC TRADE: NETWORK TOPOLOGIES FOR INTERMODULE SUBSYSTEM INTERCONNECTIONS

TRADE OPTIONS → NUMBER DESCRIPTION	OPTION 1 GRAPH (BACKBONE)	OPTION 2 MULTIPLE BUSES	OPTION 3 CHORDAL RING	OPTION 4 Conventional (Bus, Ring, Tree, Star)
PERFORMANCE PARAMETERS				
BANDWIDTH	High	Medium	Medium	Low
FAULT TOLERANCE	High	Medium	Medium	Low
MODULARITY	High	High	Low	Variable
•				
•				
•				
SAFETY IMPACTS	High Fault Tolerance	Good Fault Tolerance	Good Fault Tolerance	Unacceptable
LIFETIME IMPACTS	Expandable	Expandable	Limited Expandability	Early Obsolescence
MAINTAINABILITY IMPACTS	Satisfactory	Satisfactory	System Shutdown (?)	Variable
RELIABILITY IMPACTS	Satisfactory	Satisfactory	Satisfactory	Variable
COST	N/A	N/A	N/A	N/A
MASS	N/A	N/A	N/A	N/A
RISK	N/A	N/A	N/A	Unacceptable
APPLICABILITY TO MULTIPLE PLATFORM TYPES	High	High	Low	Low
TECHNOLOGY READINESS LEVEL	Demonstrated 1960s	Demonstrated 1970s	Not Demonstrated	Demonstrated 1960s
DEVELOPMENT SCHEDULE	Three Years	Three Years	Not Recommended	Not Recommended
DESIGN SIMPLIFICATION	Ideal for Fiber Optics	Bad for Fiber Optics	Ideal for Fiber Optics	Not Recommended
INTERRELATIONSHIPS WITH OTHER SUBSYSTEMS	Provides sufficient bandwidth, modularity and fault tolerance for any foreseeable application	High bandwidth systems impose requirement for high performance multiplexing electronics	Probably unsuited for space applications	Limited bandwidth and fault tolerance: definately not recommended.

TECHNOLOGY DISCIPLINE: DATA MANAGEMENT DATA BUS

TECHNOLOGY ADVANCEMENT GOAL: Provide interconnect technology which can handle early manned space station data communication requirements and meet long term growth requirements without

SPECIFIC TRADE: Compare Costs/Benefits of potential fiber optic data communication networks approaches. (Interconnect level only considered, System level comparisons are part of the Data Management Architecture Study)

TRADE OPTIONS → NUMBER DESCRIPTION	OPTION 1 GRAPH NETWORK	OPTION 2 CHORDAL RING NETWORK	OPTION 3 HYBRID DISCO/WDM NETWORK	OPTION 4 HYBRID DISCO/FDM NETWORK
PERFORMANCE PARAMETERS				
EFFICIENCY				
POWER CONSUMPTION	10,850 W	2,500 W	3,200 W	8060 W
OTHERS Data Rate	200 MBPS/Link 1.6 - GBPS/Network	200 MBPS/Link 200 MBPS/Network	2 to 4 GPPS combined bandwidth of 4 wavelength optical multiplex	500 MBPS - 1 GBPS combined data bandwidth of FDM & baseband portions on network.
•				
•				
•				
SAFETY IMPACTS				
LIFETIME IMPACTS				
MAINTAINABILITY IMPACTS				
RELIABILITY IMPACTS	About an order of magnitude better than options 3 & 4 due to use of LED optical source.	Same as option 2.	Reduced reliability compared to options 1 & 2 due to ILD optical source use	(Same as option 3)
COST	$8,018,120	$2,157,080	$2,304,000	$2,956,000
MASS	2604 lb	698 lb	997 lb	1926 lb
RISK	Low due to redundancy, fault tolerance	Moderate (due to potential limits on growth)	Moderate - requires active repeaters on station module/module interfaces.	(Same as option 3)
APPLICABILITY TO MULTIPLE PLATFORM TYPES	Universally Applicable	Universally Applicable		
TECHNOLOGY READINESS LEVEL	Good, mature at link level.	Good, mature at link level.	Young Technology (WDM, MDX/DEMOX) Components relatively costly.	Relatively mature technology, FDM use well proven in local area network, CATV applications.
INTERRELATIONSHIPS WITH OTHER SUBSYSTEMS	Data Management Architecture	Data Management Architecture	Data Management Architecture	Data Management Architecture
OTHER COMPARISON PARAMETERS RECONFIGURABILITY	Excellent, changes can be made while network continues to operate	Poor, addition/deletion of nodes requires careful sequencing to prevent interruption of network operation.	Excellent, nodes are effectively paralleled. Addition or deletion has no effect on network operation unless	(Same as option 3)

TECHNOLOGY DISCIPLINE: LONG LIFE THERMAL MANAGEMENT

TECHNOLOGY ADVANCEMENT GOAL: To reduce cost of long life thermal management system by minimizing the effect of thermal coating degradation.

SPECIFIC TRADE: Compare costs and benefits for three radiator configurations, with and without thermal storage and coating renewal, for 100 KW heat rejection at 50° F in low-earth orbit.

TRADE OPTIONS → NUMBER DESCRIPTION	OPTION 1 Fixed Radiator		OPTION 2 Selectable Radiators		OPTION 3 Steerable Radiator		OPTION 4 Coating Renewal (2-1/2 year cycle)	
PERFORMANCE PARAMETERS	No Storage	Storage	No Storage	Storage	No Storage	Storage	No Storage	Storage
OTHERS							Option 1 2 3	Option 1 2 3
• Radiator Area (ft^2)	95280	11960	17990	7000	9760	5090	14770 8630 5040	8670 5930 4410
• Thermal Storage (KWHR)	-	75.1	-	34.6	-	18.3	- - -	17.8 22.9 4.8
• Weight (lbs)	114300	22610	21580	12210	11710	8120	17720 10360 6050	9970 9640 5820
LIFETIME IMPACTS	5 year limit	Designed for totally degraded coating	→					
MAINTAINABILITY IMPACTS								
RELIABILITY IMPACTS	Requires radiator replacement	Minimal impact	Added values & controls for selectable radiator. Greater impact than option 1.		Steering mechanism & control plus flexible (or rotating) fluid couplings resulting great impact than Option 2		Inherent high level of maintenance for coating renewal	
COST (life cycle 25 years) $\$10^6$	320	15.8	15.1	8.5	8.2	5.7	12.4 7.3 4.3	7.0 6.7 4.1
MASS (total for life cycle) $\$10^3$ lbs	457	22.6	21.6	12.2	11.7	8.1	17.7 10.4 6.1	10.0 9.6 5.8
RISK	High	Low	Low	Low	Higher risk than 2		Cost & mass does not include renewal technique. Cost and mass risk higher than 3.	
APPLICABILITY TO MULTIPLE PLATFORM TYPES	All require radiator placement to provide relatively unobstructed view to space.							
TECHNOLOGY READINESS LEVEL	Requires replaceable radiator	Requires thermal storage development	Available	Requires storage development	Requires flexible fluid coupling development	Requires in addition thermal storage development	Requires development of coating renewal techniques	
INTERRELATIONSHIPS WITH OTHER SUBSYSTEMS	Radiator size and weight affect attitude control system. Radiator panel size affects radiation exchange with solar panels.						Coating renewal may be a contamination source for other subsystems or experiments	

TECHNOLOGY DISCIPLINE: Integration of Automated Housekeeping Functions

TECHNOLOGY ADVANCEMENT GOAL: To reduce cost of maintaining the housekeeping functions on an early manned space station while enhancing crew safety and comfort.

SPECIFIC TRADE: Compare costs and benefits of four options. (1) resupply life support & regulated power & thermal, (2) change to regenerative life support, (3) change to automated regenerative life support and (4) integrate automated regenerative life support & electrical & thermal.

TRADE OPTIONS → NUMBER DESCRIPTION	OPTION 1 Resupply Life Support	OPTION 2 Regenerative Life Support	OPTION 3 Automated Regenerative	OPTION 4 Integration of Automated H/K
PERFORMANCE PARAMETERS				
POWER CONSUMPTION	At 4000 watts	At 17,300 watts	At 19,000 watts	At 20,000 watts
OTHERS				
• Shuttle Payload	150,000 lb/year	10,000 lb/year	10,000 lb/year	8,000 lb/year
• Monitor/Control Effort	27,000 man hrs/year	220,000 man hrs/year	27,000 man hrs/year	9,000 man hrs/year
•				
SAFETY IMPACTS	Depends on shuttle flights-low	Complex syst, human monitor (some better than 1)	Complex syst with complex controller (not as good as 2)	Controller problems worked (about the same as 2)
LIFETIME IMPACTS	Simple syst should last-med.	More complex syst (not as good as 1)	Still more complex (not as good as 2)	Maintainability predictions (some better than 3)
MAINTAINABILITY IMPACTS	Simple syst fairly maintainable	More complex may be a bear (much worse than 1)	Still worse - not as good as 2	Predictors might help (some better than 3)
RELIABILITY IMPACTS	Simple syst fairly reliable if shuttle is assumed reliable	More complex - much worse than 1	Still more complex - worse than 2	About the same as 3
COST (Life Cycle Est.)	$111 million/year resupply 2.4 million/year monitor manpwr 2 million/year maintenance $115.4 million/year total est.	$ 7.1 million/year resupply 18.8 million/year monitor manpower 20 million/year maintenance $45.9 million/year total est.	$7.1 million/year resupply 12 million/year monitor manpwr 22 million/year maintenance $41.1 million/year total est.	$ 5 7 million/year resupply .8 million/year monitor manpwr 21 million/year maintenance $27.5 million/year total est.
MASS	Storage of 90 day supply air & water 38,000 lb.	On-board regenerative EC/LSS hardware & supplies = 14,000 lbs	500 lb reduction from 2 because human interfaces heavier than automatic controls = 13,500 lbs	Same as 3 = 13,500 lb
RISK	Shuttle launch dependent	High level of tech. developement	Higher level of tech. devel.	Still higher level of tech. devel.
APPLICABILITY TO MULTIPLE PLATFORM TYPES	Good	Somewhat unique	About same as 2	A little more unique than 2.
TECHNOLOGY READINESS LEVEL	It's available	Lab simulator exists extensive flight equip. devel. needed	Some thinking has been done extensive controller devel needed	Concept only Extensive integration and management controller devel.
INTERRELATIONSHIPS WITH OTHER SUBSYSTEMS	Pretty much separate	Some interrelationship in function & design	About the same as 2	More than 2