DECEMBER 1985

NASA CR-177843

MDC H1343A

SSDS

MDAC

Ford IBM RCA

SPACE STATION DATA SYSTEM ANALYSIS/ARCHITECTURE STUDY

Task 3 – Trade Studies, DR-5
Volume II

(NASA-CR-177843) SPACE STATION DATA SYSTEM ANALYSIS/ARCHITECTURE STUDY. TASK 3: TRADE STUDIES, DR-5, VOLUME 2 (McDonnell-Douglas Astronautics Co.) 298 p HC A13/MF A01 CSCL 22B G3/18

N86-20476

Unclas 04593

MCDONNELL DOUGLAS CORPORATION

SPACE STATION DATA SYSTEM ANALYSIS/ARCHITECTURE STUDY

Task 3 – Trade Studies, DR-5
Volume II

DECEMBER 1985

MDC H1343A
REPLACES MDC H1943
DATED MAY 1985

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-HUNTINGTON BEACH

5301 Bolsa Avenue Huntington Beach, California 92647 (714) 896-3311

PREFACE

The McDonnell Douglas Astronautics Company has been engaged in a Space Station Data System Analysis/Architecture Study for the National Aeronautics and Space Administration, Goddard Space Flight Center. This study, which emphasized a system engineering design for a complete, end-to-end data system, was divided into six tasks:

Task 1. Functional Requirements Definition
Task 2. Options Development
Task 3. Trade Studies
Task 4. System Definitions
Task 5. Program Plan
Task 6. Study Maintenance

McDonnell Douglas was assisted by the Ford Aerospace and Communications Corporation, IBM Federal Systems Division and RCA in these Tasks. The Task inter-relationship and documentation flow are shown in Figure 1.

This report was prepared for the National Aeronautics and Space Administration Goddard Space Flight Center under Contract No. NAS5-28082

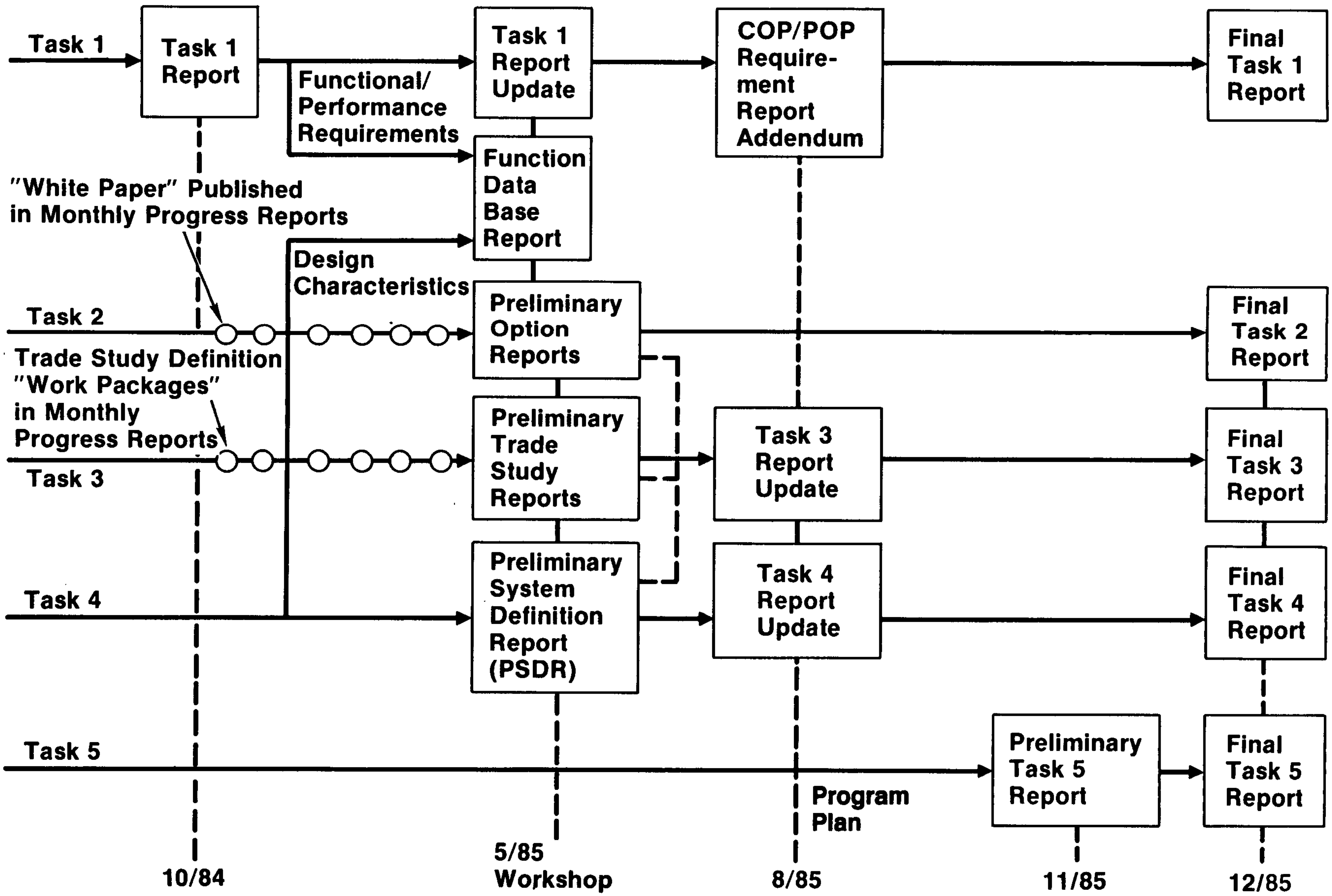
Questions regarding this report should be directed to:

Glen P. Love
Study Manager
McDonnell Douglas Astronautics Company
Huntington Beach, CA 92647
(714) 896-2292

Figure 1

VHG598

SSDS A/A DOCUMENTATION SCHEDULE



Task 3 Volume II
CONTENTS

GLOSSARY

A	Automatic
A&R	Automation and Robotics
A/A	Analysis/Architecture
A/D	Advanced Development
A/L	Airlock
A/N	Alphanumeric
AC&S	Attitude Control System
ACA	Attitude Control Assembly
ACO	Administrative Contracting Officer
ACS	Attitude Control and Stabilization
ACS/COM	Attitude Control System/Communications
ACTS	Advanced Communications Technology Satellite
AD	Ancillary Data
AD	Advanced Development
ADOP	Advanced Distributed Onboard Processor
ADP	Advanced Development Plan
AFOSR	Air Force Office of Scientific Research
AFP	Advanced Flexible Processor
AFRPL	Air Force Rocket Propulsion Laboratory
AGC	Automatic Gain Control
AGE	Attempt to Generalize
AI	Artificial Intelligence
AIE	Ada Integrated Environment
AIPS	Advanced Information Processing System
AL1	Air Lock One
ALS	Alternate Landing Site
ALS/N	Ada Language System/Navy
AMIC	Automated Management Information Center
ANSI	American National Standards Institute
AOS	Acquisition of Signal
AP	Automatic Programming
APD	Avalanche Photo Diode
APSE	Ada Programming Support Environment
ARC	Ames Research Center

PRECEDING PAGE BLANK NOT FILMED

PAGE viii INTENTIONALLY BLANK

ART	Automated Reasoning Tool
ASCII	American Standard Code for Information Exchange
ASE	Airborne Support Equipment
ASTROS	Advanced Star/Target Reference Optical Sensor
ATAC	Advanced Technology Advisory Committee
ATC	Air Traffic Control
ATP	Authority to Proceed
ATPS	Advanced Telemetry Processing System
ATS	Assembly Truss and Structure
AVMI	Automated Visual Maintenance Information
AWSI	Adoptive Wafer Scale Integration
B	Bridge
BARC	Block Adaptive Rate Controlled
BB	Breadboard
BER	Bit Error Rate
BIT	Built-in Test
BITE	Built-in Test Equipment
BIU	Buffer Interface Unit
BIU	Bus Interface Unit
BIU	Built-in Unit
BMD	Ballistic Missile Defense
BTU	British Thermal Unit
BW	Bandwidth
C	Constrained
C^2	Command and Control
C^3	Command, Control, and Communication
C^3I	Command, Control, Communication, and Intelligence
C&DH	Communications and Data Handling
C&T	Communication and Tracking Subsystem
C&T	Communications and Tracking
C&W	Control and Warning
C/L	Checklist
CA	Customer Accommodation
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAIS	Common APSE Interface Set
CAM	Computer-Aided Manufacturing

CAMAC	Computer Automatic Measurement and Control
CAP	Crew Activities Plan
CASB	Cost Accounting Standard Board
CASE	Common Application Service Elements
CATL	Controlled Aceptance Test Library
CBD	Commerce Business Daily
CBEMA	Computer and Business Equipment Manufacturing Association
CCA	Cluster Coding Algorithm
CCB	Contractor Control Board
CCB	Configuration Control Board
CCC	Change and Configuration Control
CCD	Charge-Coupled Device
CCITT	Consultive Committee for International Telegraph and Telephone
CCITT	Coordinating Committee for International Telephony and Telegraphy
CCMS	Checkout Control and Monitor System
CCR	Configuration Change Request
CCSDS	Consultative Committee for Space Data System
CCTV	Closed-Circuit Television
cd/M^2	Candelas per square Meter
CDG	Concept Development Group
CDMA	Code Division Multiple Access
CDOS	Customer Data Operations System
CDR	Critical Design Review
CDS	Control Data Subsystem
CE	Conducted Emission
CEI	Contract End-Item
CER	Cost Estimating Relationship
CFR	Code of Federal Regulations
CFS	Cambridge File Server
CG	Center of Gravity
CIE	Customer Interface Element
CIL	Critical Item List
CIU	Customer Interface Unit
CLAN	Core Local Area Network
CM	Configuration Management
CM	Center of Mass
CMDB	Configuration Management Data Base

CMG	Control Moment Gyro
CMOS	Complementary Metal-Oxide Semiconductor
CMS	Customer Mission Specialist
CMU	Carnegie-Mellon University
CO	Contracting Officer
COF	Component Origination Form
COL	Controlled Operations Library
COMM	Commercial Missions
COP	Co-orbital Platform
COPCC	Coorbit Platform Control Center
COPOCC	COP Operations Control Center
COTS	Commercial Off-the-Shelf Software
CPCI	Computer Program Configuration Item
CPU	Central Processing Unit
CQL	Channel Queue Limit
CR	Compression Ratio
CR	Change Request
CR&D	Contract Research and Development
CRC	Cyclic Redundancy Checks
CRF	Change Request Form
CRSS	Customer Requirements for Standard Services
CRT	Cathode Ray Tube
CS	Conducted Susceptibility
CSD	Contract Start Date
CSDL	Charles Stark Draper Laboratory
CSMA/CD/TS	Carrier-Sense Multiple with Access/Collision Detection and Time Slots
CSTL	Controlled System Test Library
CTA	Computer Technology Associates
CTE	Coefficient of Thermal Expansion
CUI	Common Usage Item
CVSD	Code Variable Slope Delta (Modulation)
CWG	Commonality Working Group
D&B	Docking and Berthing
DADS	Digital Audio Distribution System
DAIS	Digital Avionics Integration System
DAR	Defense Acquisition Regulation

DARPA	Defense Advanced Research Projects Agency
DB	Data Base
DBA	Data Base Administrator
DBML	Data Base Manipulation Language
DBMS	Data Base Management System
DCAS	Defense Contract Administrative Services
DCDS	Distributed Computer Design System
DCR	Data Change Request
DDBM	Distributed Data Base Management
DDC	Discipline Data Center
DDT&E	Design, Development, Testing, and Engineering
DEC	Digital Equipment Corp.
DES	Data Encryption Standard
DFD	Data Flow Diagram
DGE	Display Generation Equipment
DHC	Data Handling Center
DID	Data Item Description
DIF	Data Interchange Format
DMA	Direct Memory Access
DMS	Data Management System
DoD	Department of Defense
DOMSAT	Domestic Communications Satellite System
DOS	Distributed Operating System
DOT	Department of Transportation
DPCM	Differential Pulse Code Modulation
DPS	Data Processing System
DR	Discrepancy Report
DR	Data Requirement
DRAM	Dynamic Random-Access Memory
DRD	Design Requirement Document
DS&T	Development Simulation and Training
DSDB	Distributed System Data Base
DSDL	Data Storage Description Language
DSDS	Data System Dynamic Simulation
DSIT	Development, Simulation, Integration and Training
DSN	Deep-Space Network
DTC	Design to Cost

DTC/LCC	Design to Cost/Life Cycle Cost
DTG	Design To Grow
E/R	Entity/Relationship
EADI	Electronic Attitude Direction Indicator
ECC	Error Correction Codes
ECLSS	Environmental Control and Life-Support System
ECMA	European Computers Manufacturing Assoc.
ECP	Engineering Change Proposals
ECS	Environmental Control System
EDF	Engineering Data Function
EEE	Electrical, Electronic, and Electromechanical
EHF	Extremely High Frequency
EHSI	Electronic Horizontal Situation Indicator
EIA	Electronic Industry Association
EL	Electroluminescent
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMCFA	Electromagnetic Compatibility Frequency Analysis
EME	Earth Mean Equator
EMI	Electromagnetic Interference
EMR	Executive Management Review
EMS	Engineering Master Schedule
EMU	Extravehicular Mobility Unit
EMUDS	Extravehicular Maneuvering Unit Decontamination System
EO	Electro-optic
EOL	End of Life
EOS	Earth Observing System
EPA	Environmental Protection Agency
EPS	Electrical Power System
ERBE	Earth Radiation Budget Experiment
ERRP	Equipment Replacement and Refurbishing Plan
ESR	Engineering Support Request
ESTL	Electronic Systems Test Laboratory
EVA	Extravehicular Activity
F/T	Fault Tolerant
FACC	Ford Aerospace and Communications Corporation
FADS	Functionally Automated Database System

FAR	Federal Acquisition Regulation
FCA	Functional Configuration Audit
FCOS	Flight Computer Operating System
FCR	Flight Control Rooms
FDDI	Fiber Distributed Data Interface
FDF	Flight Dynamics Facility
FDMA	Frequency-Division Multiple Access
FEID	Flight Equipment Interface Device
FETMOS	Floating Gate Election Tunneling Metal Oxide Semiconductor
FF	Free Flier
FFT	Fast Fourier Transform
FIFO	First in First Out
FIPS	Federal Information Processing Standards
fl	foot lambert - Unit of Illumination
FM	Facility Management
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Mode Effects and Criticality Analysis
FO	Fiber-Optics
FO/FS/R	Fail-Operational/Fail Safe/Restorable
FOC	Fiber-Optic Cable
FODB	Fiber-Optic Data Bus
FODS	Fiber Optic Demonstration System
FPR	Federal Procurement Regulation
FQR	Formal Qualification Review
FSD	Full-Scale Development
FSE	Flight Support Equipment
FSED	Full Scale Engineering Development
FSIM	Functional Simulator
FSW	Flight Software
FTA	Fault Tree Analysis
FTMP	Fault Tolerant Multi-Processor
FTSC	Fault Tolerant Space Computer
GaAs	Gallium Arsenide
GaAsP	Gallium Arsenic Phosphorus
GaInP	Gallium Indium Phosphorus
GaP	Gallium Phosphorous
GAPP	Geometric Arithmetic Parallel Processor

Gbps	Gigabits Per Second
GBSS	Ground Based Support System
GEO	Geosynchronous Earth Orbit
GEP	Gas Election Phosphor
GFC	Ground Forward Commands
GFE	Government-Furnished Equipment
GFP	Government-Furnished Property
GFY	Government Fiscal Year
GIDEP	Government/Industry Data Exchange Program
GMM	Geometric Math Model
GMS	Geostationary Meteorological Satellite
GMT	Greenwich Mean Time
GMW	Generic Maintenance Work Station
GN&C	Guidance, Navigation, and Control
GPC	General-Purpose Computer
GPP	General-Purpose Processor
GPS	Global Positioning System
GRO	Gamma Ray Observatory
GSC	Ground Service Center
GSE	ground Support Equipment
GSFC	(Robert H.) Goddard Space Flight Center
GTOSS	Generalized Tethered Object System Simulation
H/W	Hardware
HAL	High-Order Algorithmic Language
HDDR	Help Desk Discrepancy Report
HDDR	High Density Digital Recording
HEP	Heterogeneous Element Processor
HFE	Human Factors Engineering
HIPO	Hierarchical Input Process Output
HIRIS	High Resolution Imaging Spectrometer
HM1	Habitation Module One
HM	Habitation Module
HOL	High Order Language
HOS	High Order Systems
HPP	High Performance Processors
HRIS	High Resolution Imaging Spectrometer
I	Interactive

I/F	Interface
I/O	Input/Output
IBM	IBM Corporation
IC	Intercomputer
ICAM	Integrated Computer-Aided Manufacturing
ICB	Internal Contractor Board
ICD	Interface Control Document
ICOT	Institute (for new generation) Computer Technology
ICS	Interpretive Computer Simulation
ID	Interface Diagram
ID	Identification
IDM	Intelligent Database Machine
IDMS	Information and Data Management System
IEEE	Institute of Electrical and Electronic Engineers
IEMU	Integrated Extravehicular Mobility Unit
IF	Intermediate Frequency
IFIPS	International Federation of Industrial Processes Society
ILD	Injector Laser Diode
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IOC	Initial Operating Capability
IOP	Input/Output Processor
IPCF	Interprocess Communications Facility
IPC	Interprocesses Communication
IPL	Initial Program Load
IPR	Internal Problem Report
IPS	Instrument Pointing System
IR	Infrared
IR&D	Independent Research and Development
IRN	Interface Revision Notices
ISA	Inertial Sensor Assembly
ISA	Instruction Set Architecture
ISDN	Integration Services Digital Network
ISO	International Standards Organization
ITAC-O	Integration Trades and Analysis-Cycle 0
ITT	International Telegraph and Telephone
IV&V	Independent Validation and Verification

IVA	Intravehicular Activity
IWS	Intelligent Work Station
JPL	Jet Propulsion Laboratory
JSC	(Lyndon B.) Johnson Space Center
KAPSE	Kernal APSE
KEE	Knowledge Engineering Environment
KIPS	Knowledge Information Processing System
KOPS	Thousands of Operations Per Second
KSA	Ku-band, Single Access
KSC	(John F.) Kennedy Space Center
Kbps	Kilobits per second
Kipc	Thousand instructions per cycle
LAN	Local-Area Network
LaRC	Langley Research Center
LCC	Life-Cycle Cost
LCD	Liquid Crystal Display
LDEF	Long-Duration Exposure Facility
LDR	Large Deployable Reflector
LED	Light-Emitting Diode
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LIDAR	Laser-Instrument Distance and Range
LIFO	Last In First Out
LIPS	Logical Inferences Per Second
LISP	List Processor
LisP	List Processor
LLC	Logical Link Control
LMI	LISP Machine Inc.
LN_2	Liquid Nitrogen
LNA	Low-noise Amplifier
LOE	Level of Effort
LOE	Low-earth Orbit Environments
LOS	Loss of Signal
LPC	Linear Predictive Coding
LPS	Launch Processing System
LRU	Line-Replaceable unit
LSA	Logistic Support Analysis

LSAR	Logistic Support Analysis Report
LSE	Language Sensity Editors
LSI	Large-scale Integration
LTV	LTV Aerospace and Defense Company, Vought Missiles Advanced Programs Division
LZPF	Level 0 Processing Facility
M	Manual
µP	Microprocessor
MA	Multiple Access
MA	Managing Activity
MAPSE	Minimum APSE
Mbps	Million Bits Per Second
MBPS	Million Bits Per Second
MCAIR	McDonnell Aircraft Company
MCC	Mission Control Center
MCC	Microelectronics and Computer Technology Corp.
MCDS	Management Communications and Data System
MCM	Military Computer Modules
MCNIU	Multi-compatible Network Interface Unit
MDAC-HB	McDonnell Douglas Astronautics Company-Huntington Beach
MDAC-STL	McDonnell Douglas Astronautics Company-St. Louis
MDB	Master Data Base
MDC	McDonnell Douglas Corporation
MDMC	McDonnell Douglas Microelectronics Center
MDRL	McDonnell Douglas Research Laboratory
MFLOP	Million Floating Point Operations
MHz	Million Hertz
MIMO	Multiple-Input Multiple-Output
MIPS	Million (machine) Instructions Per Second
MIT	Massachusetts Institute of Technology
MITT	Ministry of International Trade and Industry
MLA	Multispectral Linear Array
MMI	Man Machine Interface
MMPF	Microgravity and Materials Process Facility
MMS	Module Management System
MMS	Momentum Management System
MMU	Mass Memory Unit

MMU	Manned Maneuvering Unit
MNOS	Metal-Nitride Oxide Semiconductor
MOC	Mission Operations Center
MOI	Moment of Inertia
MOL	Manned Orbiting Laboratory
MOS	Metal Oxide Semiconductor
MPAC	Multipurpose Application Console
MPS	Materials, Processing in Space
MPSR	Multi-purpose Support Rooms
MRMS	Mobile Remote Manipulator System
MRWG	Mission Requirements Working Group
MSFC	(George C.) Marshall Space Flight Center
MSI	Medium-Scale Integration
MSS	Multispectral Scanner
MTA	Man-Tended Approach
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
MTU	Master Timing Unit
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network
NASPR	NASA Procurement Regulation
NBO	NASA Baseline
NBS	National Bureau of Standards
NCC	Network Control Center
NFSD	NASA FAR Supplement Directive
NGT	NASA Ground Terminals
NHB	NASA Handbook
NISDN	NASA Integrated System Data Network
NIU	Network Interface Unit
NL	National Language
NLPQ	National Language for Queuing Simulation
NMI	NASA Management Instruction
NMOS	N-Channel Metal-Oxide Semiconductor
NMR	N-Modular Redundant
NOS	Network Operating System
NS	Nassi-Schneidermann
NSA	National Security Administration

NSF	National Science Foundation
NSTS	National Space Transportation System
NTDS	Navy Tactical Data System
NTE	Not To Exceed
NTRL	NASA Technology Readiness Level
NTSC	National Television Standards Committee
Nd:YAG	Neodynium Yttrium Aluminum Garnet (laser type)
O&M	Operations and Maintenance
O/B	Onboard
OASCB	Orbiter Avionics Software Control Board
OCN	Operations and Control Network, Operational Control Networks
ODB	Operational Data Base
ODBMS	Onboard Data Base Management System
OEL	Operating Events List
OES	Operating Events Schedule
OID	Operations Instrumentation Data
OLTP	On Line Transaction Processing
OMCC	Operations Management and Control Center
OMV	Orbital Maneuvering Vehicle
ONR	Office of Naval Research
ORU	Orbital Replacement Unit
OS	Operating System
OSE	Orbit Support Equipment
OSI	Open Systems Interconnect
OSM	Orbital Service Module
OSSA	Office of Space Science and Applications
OSTA	Office of Space and Terrestrial Application
OSTDS	Office of Space Tracking and Data Systems
OTV	Orbital Transfer Vehicle
P&SA	Payload and Servicing Accommodations
P/L	Payload
PA	Product Assurance
PAM	Payload Assist Module
PASS	Primary Avionics Shuttle Software
PBX	Private Branch Exchange
PC	Personal Computer
PCA	Physical Configuration Audit

PCA	Program Change Authorization
PCM	Pulse Code Modulation
PCR	Program Change Request
PDP	Plazma Display Panel
PDR	Preliminary Design Review
PDRD	Program Definition and Requirements Document
PDRSS	Payload Deployment and Retrieval System Simulation
PILS	Payload Integration Library System
PIN	Personal Identification Number
PLA	Programmable Logic Array
PLAN	Payload Local Area Network
PLSS	Payload Support Structure
PMAD	Power Management and Distribution
PMC	Permanently Manned Configuration
PN	Pseudonoise
POCC	Payload Operations Control Center
POP	Polar Orbiter Platform
POPCC	Polar Orbit Platform Control Center
POPOCC	POP Operations Control Center
PRISM	Prototype Inference System
PSA	Problem Statement Analyzer
PSA	Preliminary Safety Analysis
PSCN	Program Support Communications Network
PSL	Problem Statement Language
PTR	Problem Trouble Report
QA	Quality Assurance
R	Restricted
R&D	Research and Development
R&QA	Reliability and Quality Assurance
R/M/A	Reliability/Maintainability/Availability
R/T	Real Time
RAD	Unit of Radiation
RAM	Random Access Memory
RAP	Relational Associative Processor
RC	Ring Concentrator
RCA	RCA Corporation
RCS	Reaction Control System

RDB	relational Data Base
RDC	Regional Data Center
REM	Roentgen Equivalent (man)
RF	Radio Frequency
RFC	Regenerative Fuel Cell
RFI	Radio Frequency Interference
RFP	Request for Proposal
RGB	Red-Green-Blue
RID	Review Item Disposition
RID	Revision Item Description
RISC	Reduced Instruction Set Computer
RMS	Remote Manipulator System
RMSE	Root Mean Square Error
RNET	Reconfiguration Network
ROM	Read Only Memory
ROTV	Reuseable Orbit Transfer Vehicle
RPMS	Resource Planning and Management System
RS	Reed-Solomon
RSA	Rivest, Skamir and Adleman (encryption method)
RTX	Real Time Execution
S&E	Sensor and Effector
S/C	Spacecraft
S/W	Software
SA	Single Access
SA	Structured Analysis
SAAX	Science and Technology Mission
SAE	Society of Automotive Engineers
SAIL	Shuttle Avionics Integration Laboratory
SAIS	Science and Applications Information System
SAR	Synthetic Aperture Radar
SAS	Software Approval Sheet
SASE	Specific Application Service Elements
SATS	Station Accommodations Test Set
SBC	Single Board Computer
SC	Simulation Center
SCR	Software Change Request
SCR	Solar Cosmic Ray

SCS	Standard Customer Services
SDC	Systems Development Corporation
SDP	Subsystem Data Processor
SDR	System Design Review
SDTN	Space and Data Tracking Network
SE&I	Systems Engineering and Integration
SEI	Software Engineering Institute
SESAC	Space and Earth Scientific Advisory Committee
SESR	Sustaining Engineering System Improvement Request
SESS	Software Engineering Standard Subcommittee
SEU	Single Event Upset
SFDU	Standard Format Data Unit
SI	International System of Units
SIB	Simulation Interface Buffer
SIFT	Software Implemented Fault Tolerance
SIMP	Single Instruction Multi-Processor
SIRTF	Shuttle Infrared Telescope Facility
SLOC	Source Lines of Code
SMC	Standards Management Committee
SMT	Station Management
SNA	System Network Architecture
SNOS	Silicon Nitride Oxide Semiconductor
SNR	Signal to Noise Ratio
SOA	State Of Art
SOPC	Shuttle Operations and Planning Complex
SOS	Silicon On Saphire
SOW	Statement of Work
SPC	Stored Payload Commands
SPF	Software Production Facility
SPF	Single-Point Failure
SPR	Spacelab Problem Reports
SPR	Software Problem Report
SQA	Software Quality Assurance
SQAM	Software Quality Assessment and Measurement
SQL/DS	SEQUEL Data System
SRA	Support Requirements Analysis
SRAM	Static Random Access Memory

SRB	Software Review Board
SRC	Specimen Research Centrifuge
SREM	Software Requirements Engineering Methodology
SRI	Stanford Research Institute
SRM&QA	Safety, Reliability, Maintainability, and Quality Assurance
SRMS	Shuttle Remote Manipulator System
SRR	System Requirements Review
SS	Space Station
SSA	Structural Systems Analysis
SSA	S-band Single Access
SSCB	Space Station Control Board
SSCC	Station Station Communication Center
SSCR	Support Software Change Request
SSCS	Space Station communication system
SSCTS	Space Station communications and tracking system
SSDMS	Space Station data management system
SSDR	Support Software Discrepancy Report
SSDS	Space Station data system
SSE	Software Support Environment
SSEF	Software Support Environment Facility
SSIS	Space Station Information System
SSME	Space Shuttle Main Engine
SSO	Source Selection Official
SSOCC	Space Station Operations Control System
SSOCC	Space Station Operations Control Center
SSOL	Space Station Operation Language
SSON	Spacelab Software Operational Notes
SSOS	Space Station Operating System
SSP	Space Station Program
SSPE	Space Station Program Element
SSPO	Space Station Program Office
SSSC	Space Station Standard Computer
SSST	Space Station System Trainer
STAR	Self Test and Recovery (repair)
STARS	Software Technology for Adaptable and Reliable Software
STDN	Standard Number
STI	Standard Technical Institute

STO	Solar Terrestrial Observatory
STS	Space Transportation System
SUSS	Shuttle Upper Stage Systems
SYSREM	System Requirements Engineering Methodology
Si	Silicon
SubACS	Submarine Advanced Combat System
TAI	International Atomic Time
TBD	To Be Determined
TBU	Telemetry Buffer Unit
TC	Telecommand
TCP	Transmissions Control Protocols
TCS	Thermal Control System
TDASS	Tracking and Data Acquisition Satellite System
TDM	Technology Development Mission
TDMA	Time-Division Multiple Access
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TFEL	Thin Film Electrolumenescent
THURIS	The Human Role in Space (study)
TI	Texas Instruments
TM	Technical Manual
TM	Thematic Mapper
TMDE	Test, Measurement, and Diagnostic Equipment
TMIS	Technical and Management Information System
TMP	Triple Multi-Processor
TMR	Triple Modular Redundancy
TMS	Thermal Management System
TPWG	Test Planning Working Group
TR	Technical Requirement
TRAC	Texas Reconfigurable Array Computer
TRIC	Transition Radiation and Ionization Calorimeter
TSC	Trade Study Control
TSIP	Technical Study Implementation Plan
TSP	Twisted Shielded Pair
TSS	Tethered Satellite System
TT&C	Telemetry, Tracking, and Communications
TTC	Telemetry Traffic Control

TTR	Timed Token Ring
TWT	Traveling-Wave Tube
U	Non-restrictive
UCC	Uniform Commercial Code
UDRE	User Design Review and Exercise
UIL	User Interface Language
UON	Unique Object Names
UPS	Uninterrupted Power Source
URN	Unique Record Name
UTBUN	Unique Telemetry Buffer Unit Name
UTC	Universal Coordinated Time
V&V	Validation and Verification
VAFB	Vandenberg Air Force Base
VAX	Virtual Address Exchange
VHSIC	Very High-Speed Integrated Circuit
VLSI	Very Large-Scale Integration
VLSIC	Very Large-Scale Integrated Circuit
VV&T	Validation, Verification and Testing
WAN	Wide Area Network
WBS	Work Breakdown Structure
WBSP	Wideband Signal Processor
WDM	Wavelength Division Multiplexing
WP	Work Package
WRO	Work Release Order
WS	Workstation
WSGT	White Sands Ground Terminal
WTR	Western Test Range
XDFS	XEROX Distributed File System
YAPS	Yet Another Production System
ZOE	Zone Of Exclusion
ZONC	Zone Of Non-Contact
ZnS	Zinc Sulfide

Volume II

TASK 3 - TRADE STUDIES

This volume contains trade studies for Section IX through Section XVII of the Trade Studies Report. Table 1 lists all trade studies by subject for both Volumes I and II. The reader is referred to the introductory sections of Volume I relating to the methodology for conducting the trade studies.

Table 1

	SECTION	TRADE STUDY
VOLUME I	I.	SPACE AUTONOMY AND FUNCTION AUTOMATION
	II.	SOFTWARE TRANSPORTABILITY
	III.	SYSTEM NETWORK TOPOLOGY
	IV.	COMMUNICATIONS STANDARDIZATION
	V.	ONBOARD LOCAL AREA NETWORKING
	VI.	DISTRIBUTED OPERATING SYSTEM
	VII.	SOFTWARE CONFIGURATION MANAGEMENT
	VIII.	SOFTWARE DEVELOPMENT ENVIRONMENT FACILITY
VOLUME II	IX.	SOFTWARE DEVELOPMENT TEST & INTEGRATION CAPABILITY
	X.	FAULT TOLERANT COMPUTING
	XI.	SPACE QUALIFIED COMPUTERS
	XII.	DISTRIBUTED DATA BASE MANAGEMENT SYSTEM
	XIII.	SYSTEM INTEGRATION TEST AND VERIFICATION
	XIV.	CREW WORKSTATION
	XV.	MASS STORAGE
	XVI.	COMMAND AND RESOURCE MANAGEMENT
	XVII.	SPACE COMMUNICATIONS

IX. SOFTWARE DEVELOPMENT TEST & INTEGRATION CAPABILITY

SOFTWARE DEVELOPMENT,
TEST AND INTEGRATION CAPABILITY TRADE STUDY

1.0 INTRODUCTION

The purpose of this trade study is to compare and contrast three methods of providing a test and integration capability. Since more knowledge about the DMS will need to be known before one method can be determined to be better than the other, this trade study will concentrate on comparing and contrasting the different options under various assumptions.

The trades study will only directly address the onboard data management system including core subsystems and payload applications. Associated space vehicles and ground systems are not directly addressed. However, one of the trade study criteria is to evaluate the options for expandability and flexibility so that they could be used for testing of future systems such as the ground system, free flyers, etc.

1.1 BACKGROUND

The Space Station data processing system will be large, complex and distributed. The test and integration capability must be able to support execution of a large amount of code. Because the system will be distributed the test facility must support concurrent processes and multiple processors while providing diagnostic control over all processes. It must provide this diagnostic control without seriously affecting the system timing and synchronization. The communication between the processors will involve a high volume of bus traffic that must be monitored and diagnosed. Finally, since the software for the system will be developed by multiple contractors, the test and integration capabilities must support a coordinated effort.

1.2 ISSUES

The creation of an adequate test and integration capability for a distributed system will be difficult and some of the reasons are:

1. The systems will be complex.
2. Multiple processors must be observed (dispersed test objects).
3. Concurrent processing must be observed.
4. System timing and synchronization must be preserved.
5. There will be a high volume of bus traffic (large amounts of I/O).
6. The software integration will involve software from many different contractors.
7. Test methodologies for distributed system are not well developed or mature.

The test and integration capability may have additional problems to address due to some of the specific characteristics of the Space Station system. Some of these problems could be:

1. Lack of sufficiently available target hardware for testing purposes.
2. Lack of appropriate test connectors and other diagnostic equipment to be provided with the processor hardware.
3. Lack of commercially available diagnostic hardware and software packages for use with the target hardware.
4. Use of multiple kinds of processors.
5. Use of multiple programming languages.

An additional known issue specific to the Space Station system is the requirement to be flexible and expandable enough to support technology insertion and to be reusable for other future space systems.

1.3 TRADE STUDY CRITERIA

1.3.1 GENERIC

1.3.1.1 COSTS

DEVELOPMENT(NON-RECURRING): These include all costs to design and build the first working system.

UNIT(RECURRING): These include costs for providing additional working systems.

LIFE CYCLE: These include all costs to maintain working systems, train new users to test software using the systems, and providing user assistance.

1.3.1.2 RISK

DEVELOPMENT(TECHNOLOGY READINESS, DESIGN DIFFICULTY): There is an amount of risk involved in projecting what the current technology will be when the system is designed.

PRODUCTION(PRODUCIBILITY, COST/SCHEDULE, ETC): There is also an amount of risk in projecting the state of technologies (such as high speed processors, etc.) that will exist when the test system is put into use.

1.3.1.3 PERFORMANCE

This criterion addresses the effectiveness of the testing system resulting from a given method. For example, the test system could be ineffective because of being finished too late for software development, insufficient capability, poor availability, etc. The test system would be effective if it finds errors, is user friendly, and is cost effective to build and operate.

1.3.1.4 STANDARDIZATION/COMMONALITY

The possibility of using common available hardware and software will be considered. In general providing common (and possibly commercially available) hardware and software building blocks for the system will reduce cost, training and maintenance.

1.3.1.5 GROWTH/TECHNOLOGY INSERTION POTENTIAL

The flexibility of the systems resulting from each method will be considered. This includes the flexibility to:

1. Upgrade to new target hardware
2. Expand the capability of the test system (insert new test equipment technologies)
3. Test systems other than Space Station

1.3.2 TRADE STUDY UNIQUE

1.3.2.1 LOANER SET POTENTIAL

For off site testing the SSE must provide a "loaner set". This is a minimum test capability so that testing can be done at contractor software development sites. It is to be a stand-alone autonomous test facility. The cost of providing a "loaner set" based on a given option will be considered.

1.3.2.2 DISTRIBUTED SYSTEM APPLICABILITY

Distributed systems testing is a very immature technology so there will be an amount of risk with each method. Relative risks of the methods will be indicated during the comparison. The three levels of risk considered are:

1. Risk of resulting in an unusable system.
2. Risk of resulting in a poorly usable system.
3. Risk of resulting in an unmaintainable or expensive system.

1.4 APPLICABLE OPTION PAPERS

- Software Development Options White Paper - SSDS A/A study task 2

1.5 ALTERNATIVES

The three options compared are

1. Executing the software in an emulation of the target hardware(1).
2. Executing the software in the target hardware.
3. Executing the software in an facility that is partly target hardware and partly emulated target hardware.

---

1 For the remainder of this paper TARGET HARDWARE will be defined to be the expected Space Station Data Management processors. These are the Bus Interface Units, Subsystem Data Processors and any unique processors that might be present for specific application software.

2.0 METHODOLOGY

Background information was obtained by studying the papers listed in the reference section and from experience with the following projects.

- o FSD Houston Onboard Shuttle Systems
- o FSD Manassas SUBACS Project
- o KSC Launch Processing System
- o JSC Advanced Project Simulation Interface Buffer (SIB) Study

Next, for each option, the operational concept for the Space Station system was studied and compared to previous project experience using the trade study criteria.

3.0 RESULTS

3.1 BASIC SUMMARY

The main advantages of the emulation strategy are:

- o It allows a great amount of control over the execution of the target code.

- o By not requiring the use of any special hardware, this strategy is very available. Since the test facility is just software, it can be used by many people at the same time at any location where there is a supporting host computer. For very low level testing such as unit testing the tests might be run on an intelligent workstation.

- o The technology for building an emulation test facility is known.

The main disadvantages of the emulation strategy are:

- o It requires a significant amount of software development to build the emulator. This relates to a fairly high development cost.

- It is not flexible. If the target hardware (instruction set architecture) changes then so must the emulator. This relates to high maintenance costs.

- It requires an extensive amount of cpu time per amount of simulated run time. If long simulations are desired then this relates to a high operational cost.

- It does not provide a realistic operating environment.

The main advantages of target hardware use are:

- If the real hardware is available then this would be the easiest facility to setup. However unless special hardware and software is added to provide diagnostics, this is unsuitable for testing. For a distributed system there are some fundamental difficulties(2) in developing add-ons to the target hardware to develop a usable test facility.

- The real hardware obviously provides a more realistic test facility. However all the add-ons tend to decrease the realism.

The main disadvantages of target hardware use are:

- If the target hardware is not available until late into the development/integration cycle then this strategy is not viable.

- The configured target hardware system may be very expensive to provide in a reasonable quantity so that it will be available to all testers. This relates to either a high operational cost or poor availability.

- It will be very difficult to obtain a controlled test capability (e.g., diagnostics may alter the timing of software execution in target hardware).

---

2 VISIBILITY INTO THE INTERNAL OPERATION OF A DISTRIBUTED PROCESSING SYSTEM by L. Killingbeck IRAD project 4H02

The main advantages of target hardware/emulation combination are

- o It provides a number of design options that may help reduce the development risk and cost.

- o A capability based on this option could be expanded so that problems found when software is operating in a target hardware processor could be diagnosed in by running the software in an emulator while the rest of the system is in target processors.

The main disadvantages of target hardware/emulation combination are

- o It requires an amount of new technology to interface an emulating processor with a real hardware processor.

- o Since both hardware and emulation are used this option, it has the combined disadvantages of the first two options.

3.2 BACKGROUND INFORMATION

3.2.1 EMULATION

The emulation strategy for an test and integration capability would involve no use of the target hardware during testing. Instead, an emulation of the target hardware would be used. A software program would simulate execution of instructions of the SDP or BIU in a host computer. This is depicted in Figure 1. The Shuttle Primary software has had experience using a test capability based on an emulation approach. The onboard operating system (FCOS) was first tested using a capability that was called Interpretive Computer Simulation (ICS). The emulation portion of ICS was developed by the designers of the onboard computer (AP-101) to test the design of the AP-101. It modeled the internal logic of the computer. This emulator was brought to Houston where additional diagnostic features and a user interface were added. ICS was then used by the developers of the operating system, who were coding in assembly language, to test their software. This method of testing worked very well. The diagnostic features provided allowed the developers to test and debug their software very effectively.

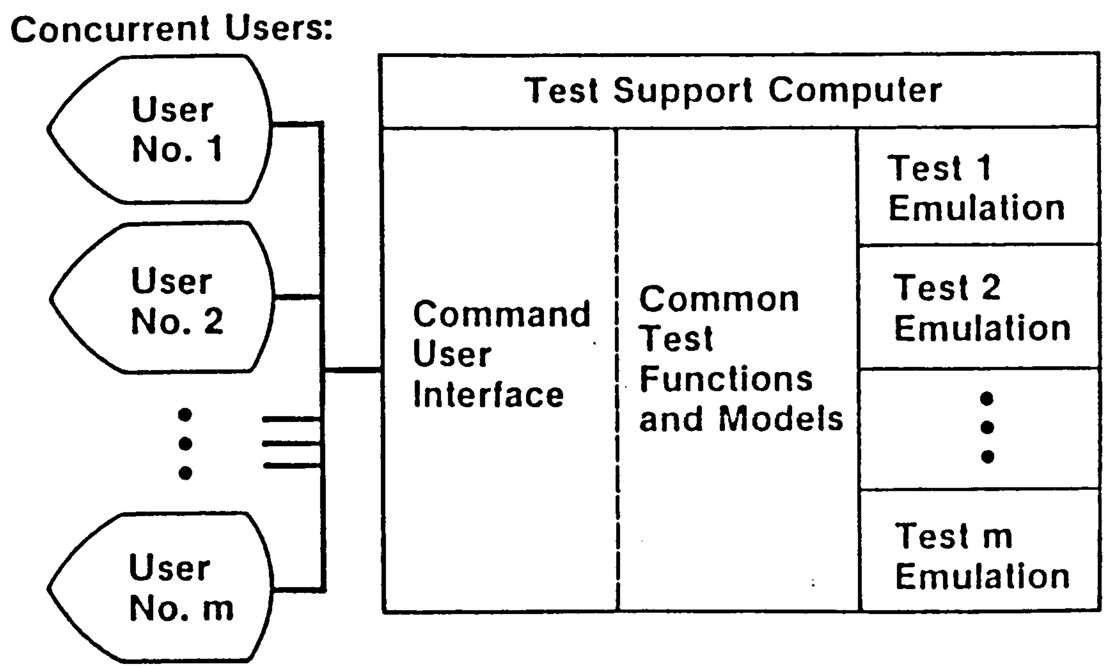


Figure 1. Emulation option configuration

There were some disadvantages to using ICS. It was very slow. The run ratio (amount of host cpu time per time of simulation) varied but was about 100 to 1 (on an IBM S360/75). This was not a significant problem as long as the tests were only a few seconds in length which was all that was initially needed by the operating system developers. Another disadvantage was that no environmental or sensor/effector modeling was supplied. This again was not a significant problem to the initial operating system testing. However application developers need longer test run times and modeling capabilities to do their testing.

Another test facility was provided for application developers. This was called Functional Simulator (FSIM). The application developers did their programming in a high level language and could compile their source code into the host native code for execution. Since the real operating system could not be supplied because it was written in AP-101 assembly language, a model of the operating system was supplied. This caused some difficulty because operating system development was still going on after FSIM was developed. Thus the modeled operating system did not always match the real operating system.

3.2.2 TARGET HARDWARE USAGE

This option would involve executing the software in the actual target hardware. Additional special hardware devices would need to be attached to the target hardware to provide diagnostics. This is depicted in Figure 2.

While ICS and FSIM were being used to do Shuttle testing, another test facility was being developed. This new test facility involved using an AP-101 computer (GPC) and Input/Output Processor (IOP). The GPC was supplied with what was called a test connector (or AGE connector). This was used by the hardware developers to do hardware testing. A device called a Flight Equipment Interface Device (FEID) was built that interfaced both the GPC via its test connector and the IOP via its ports to the host computer. This setup allowed stop/starting of the GPC/IOP, access to their memory and general

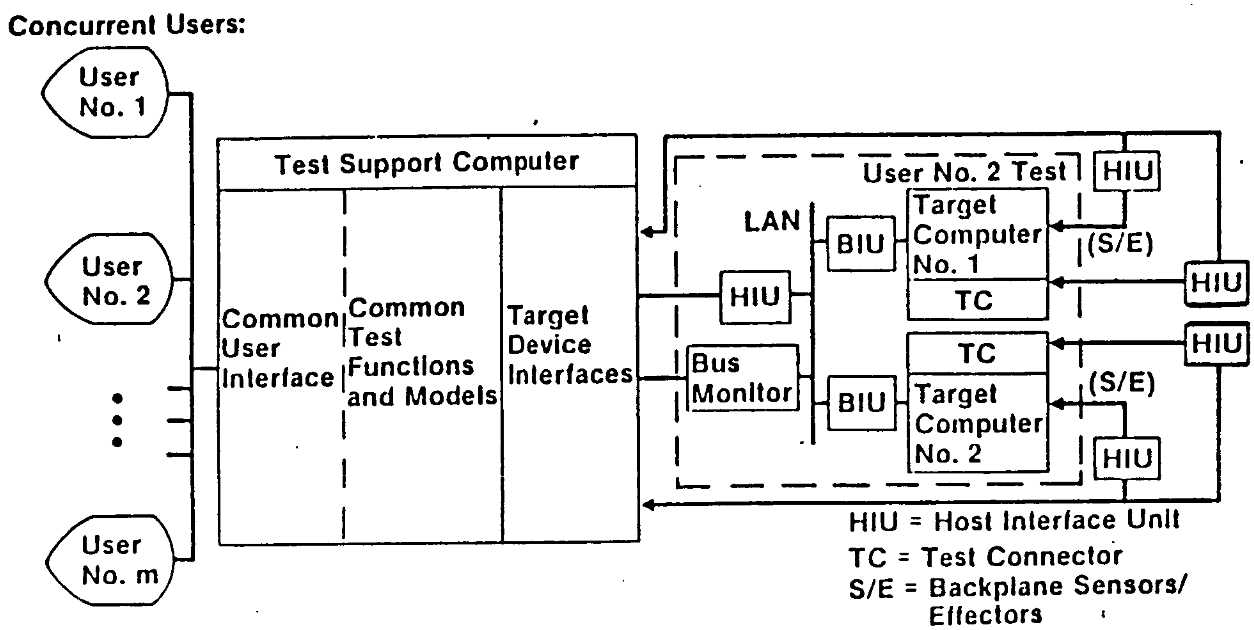


Figure 2. Maximum Flight Hardware option configuration

I/O capability. The host ran all the simulator models that generated inputs for the GPC/IOP, software that interfaced the models and the FEID, and software that interfaced with the FEID to perform diagnostic actions. This setup allowed the target processors to be used for testing while allowing a very large amount of diagnostic and simulation capability. The run ratios for this setup are close to real time.

The FEID setup is a fairly complex and expensive test facility. For the majority of the time that development and test were being done only three FEIDs were available. A facility such as this may not be practical to provide in a 'loaner set'.

There are a significant number of difficulties in using a test facility such as this for testing a distributed system. A distributed system would involve a number of processors. Stopping and starting these processors without severely affecting the timing and synchronization of the system would be extremely difficult. There is also a problem with losing I/O. When the processors are stopped, the data coming to it on the bus must be captured until the processor begins receiving again. Even then the processor must catch up on all the data it missed. This will be a serious problem because of the high volume of bus traffic anticipated in the Space Station system.

Another problem would arise if the target processors do not have AGE test connectors such as the AP-101 had. There were also a number of other features(2) that the AP-101 provided that were taken advantage of in the development of the FEID. The lack of any one of these would make the development of this type of test capability more difficult.

3.2.3 EMULATION AND TARGET HARDWARE USAGE

This option involves combining the previous two options. The testing would be done in a configuration where some of the hardware is emulated and the rest is actual target hardware. Additional hardware and software may be needed to achieve emulation/target hardware communication. This is depicted in Figure 3. There is no direct experience with using such a system.

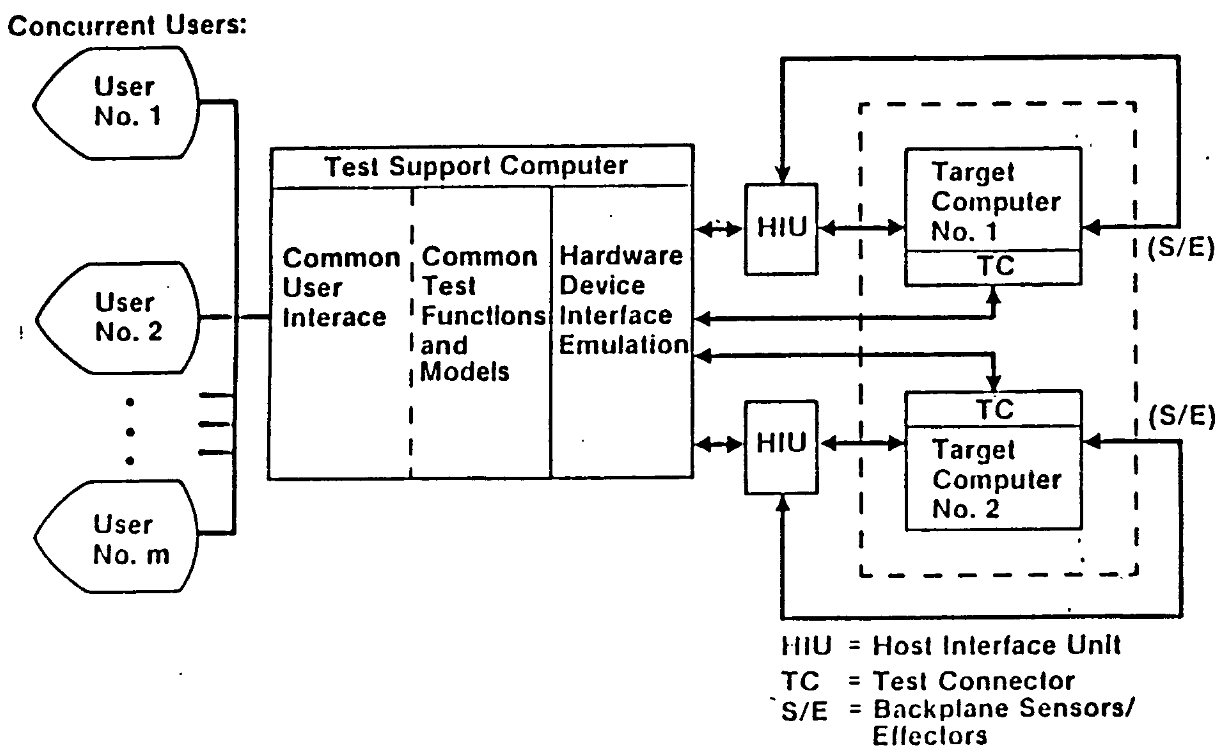


Figure 3. Combination flight Hardware/Emulation option configuration

A test capability based on this approach would involve processor emulation software running in the host along with the models, etc. An interface device would connect the host and target processor. Some of the software being tested would run in the emulator and the rest would run on the target processor. An example of this would be using a target hardware subsystem data processor with the BIU and other necessary processors being emulated on the host. When using this capability, the software that is being tested would be execute in the emulator. The emulator usually can provide much better diagnostic capability than the target hardware approach. Since the software running in the target processor is not the primary test software, less diagnostic hardware would be required for the target processor.

One of the desired capabilities for the integration test facility(3) is the following. Suppose during integration testing a problem is isolated to the software in a particular subsystem. And to diagnose the problem requires more diagnostic capability than is available with the current configuration. The test is reconfigured so that the suspect subsystem is running with detailed diagnostics while the rest of the system is running as before. The part emulation and part target hardware approach would provide this capability. The suspect subsystem could be taken out of a target processor and run in the host emulator while the rest of the system continued to run in the target hardware.

This approach would be much more flexible while combining the advantages of the other two options. However a capability based on this approach would be much more difficult to design and develop. It would require a large dedicated amount of host cpu to allow the emulation to run at least as fast as real time so that it would not be necessary to stop the target hardware. If this is not possible and it is necessary to stop the target hardware, then this would require the special hardware be used to start and stop the target hardware. The problems in doing this were discussed earlier.

---

3 · TESTING SOFTWARE IN A TACTICAL BUS-ORIENTED DISTRIBUTED SYSTEM, Richard F. Rashid and Charles V. Webber, IBM IRAD Project 2M45

3.3 OPTIONS COMPARISONS

The purpose of test and integration is to find errors in the interfaces/ communication structure between software modules of a system. When the modules are interfacing across multiple processes of a distributed system, integration testing becomes a very challenging and important task. It is challenging because of the difficulty in creating an adequate test capability. It is important because of the likelihood of having errors and the difficulty in locating the specific errors later in system testing. The likelihood of having errors in the design and code of the distributed functions is high because designing distributed systems is an immature technology(3).

Each option has an amount of risk involved. Each would require a significant amount of time and resources to develop.

The significant development item for the emulation approach would be the development of the software that emulates the target processor. The technology for doing this is known so there is little risk of failing to develop a usable system with this approach. There would be a very significant amount of manpower needed to design and code the emulator(s). However it is likely that an emulator can be acquired, as it was for Shuttle, from the hardware developers.

3.3.1 EMULATION

Since an emulator would not require target hardware, the cost required to supply additional test facilities based on this approach would be small. The only significant cost item is the amount of CPU required to actually run the emulator.

The potential negative aspects are the following. If only enough CPU could be supplied to run the emulator at many times more than real time, then the test capability would be a poorly usable one. As hardware changed, the emulator(s) would need to also be changed to correctly model the hardware. Also each new type of processor added to the system would require the development of another emulator. This, combined with the complexity of the emulators, might create a significant maintenance expense. There is a risk in using an emulation test capability in that the emulator would not correctly model the hardware and the software system might work correctly on the emulator but not work correctly on the actual hardware.

3.3.2 TARGET HARDWARE USAGE

There are many significant development items necessary to implement a test capability that had maximal use of the target processors. Several special hardware devices would need to be developed to provide diagnostic capabilities. The additional hardware would require a significant amount of software to allow users to run test cases using them as the Shuttle project FEIDs did. Each of these different devices and their associated hardware would involve their own amount of development cost and risk. The test facility as a whole would require the development of new technology. For example it is not currently known how to stop/start a distributed system without seriously affecting the timing of the system.

There is some risk that a test facility based on this approach might not be able to preserve system timing and thus might not be usable at all. There is some risk that it might not provide enough diagnostic capability thus preventing the detection of serious problems until late into the integration, or they might not be detected at all. Thus it might be a very poorly usable system. The cost of supplying additional test facilities based on this approach would be large. For each additional test facility, target processors and special diagnostic hardware devices would need to be supplied. The diagnostic hardware would likely be expensive to provide since it is not off the shelf. Each development group will likely require different mixes and numbers of processors to do their testing. Rather than providing each contractor with a common test capability that would have all they would need and more, it may be necessary (for the sake of cost) to provide contractors with a customized test facility. As new types of processors are inserted into the system or new technology is inserted, new problems will need to be addressed to preserve the use of the test facility.

3.3.3 EMULATION AND TARGET HARDWARE USAGE

The combined target hardware/emulation approach could be implemented at different levels. To provide the option to use the target hardware or an emulation of each type of processor would require as much development effort, risk, and cost as both previous options combined. An alternative level of use of this approach would be to first use what is available or is easily developed. Whatever emulators were already available would be used. An attempt would be made to use all easily available target hardware. If a problem were encountered in developing a portion of the test capability using target hardware, an emulator could be developed instead.

If the host/target hardware interface technology were sufficiently advanced, this option would provide the least development risk because it offers more design options. To supply facilities of this type for contractors to use would cost less than the full target hardware option but more than the full emulation option. Since there is a significant amount of both software and hardware to be maintained, this option would result in a high maintenance cost.

4.0 CONCLUSIONS

In the past software testing and simulations have been done in the same test environment. Because of the problems in creating a distributed simulation capability that supports all the diagnostic capabilities needed for software testing, the two activities may have to be separated.

In the lower levels of integration testing when the processing being tested is contained in a single computer, the testing can proceed in a conventional manner using either emulation or the target hardware. Once the level of integration reaches a point where a high volume of data is passed between processes operating in different computers, then conventional means using the actual target hardware may be inadequate for software testing. Instead there are several alternatives that can be used.

- The system to be tested can be designed so that the functions do not heavily share data across processors. Clean interfaces can be designed so that the software in each processor can be tested independently. No integration testing, other than simulation runs for acceptance testing, is necessary for these higher,levels of integration.

- If the system must be tested using detailed diagnostics and multiple processors (because of the criticality of the software or because it is the network operating system), then there are two possibilities. First the testing could be done using a complete emulation approach. Second, the necessary diagnostic features could be built into the system being designed. For example, detailed error logs could be kept by the system and at specific time could log it to an external device for analysis. The actual target hardware can still be used with special purpose hardware to do simulations. These simulations may not support diagnostic capabilities necessary for detailed software testing.

5.0 REFERENCES

The following papers were studied (note that literature on this subject is not widely available).

- VISIBILITY INTO THE INTERNAL OPERATION OF A DISTRIBUTED PROCESSING SYSTEM, L. Killingbeck, IBM IRAD Project 4H02.

- TESTING SOFTWARE IN A TACTICAL BUS-ORIENTED DISTRIBUTED SYSTEM, Richard F. Rashid and Charles V. Webber, IBM IRAD Project 2M45

X. FAULT TOLERANT COMPUTING

FAULT TOLERANT COMPUTING TRADE STUDY

1.0 INTRODUCTION

The fault tolerance requirements of the Space Station cannot be met by the use of a single processing unit, because of the possibility of losing that single unit through component failure or physical damage. This report compares several redundancy techniques which can be used to tolerate faults in computing systems. Since selection of a particular technique depends on the needs of individual applications, the report is organized to show the methods available for an application to meet its fault tolerance criteria.

1.1 BACKGROUND

The Space Station will have subsystems with a wide variety of requirements for fault tolerance. The basic requirement in the Phase B RFP is that all subsystems which are safety critical (category 1) or mission critical (category) will be fail-operational/fail-safe/restorable (FO/FS/R); i.e., fully operational after one failure and operate in a safe mode after two failures of the subsystem with the capability to manually restore full operational capability. Subsystems which are not safety or mission critical are classified in an "other" category (category 3) and are required to be fail safe.

The active redundancy implicit in FO/FS/R requires the use of multiple copies of the critical subsystem elements, which in turn implies penalties of power, volume, mass and other physical properties, all of which are limited resources onboard the Space Station. Therefore, less critical subsystems are expected to use lower levels of active redundancy resulting in, either a lower probability of isolating the fault to a particular unit or a lower probability of detecting the fault in the first place. The time needed to recover from a failure also varies with the particular implementation of fault tolerance, ranging from sub-seconds for high redundancy levels of active systems to minutes or hours for physical replacement of units.

PRECEDING PAGE BLANK NOT FILMED

1.2 ISSUES

The basic issues of fault tolerance are:

- o man-tended versus manned operation
- o the number of faults which must be tolerated
- o whether these faults must be tolerated simultaneously, or whether repair or replacement of the fault unit is allowed between failures
- o the time to recover from a fault
- o the probability of detecting a fault
- o the probability of isolating the failed unit after a fault is detected
- o the nature of the faults to be considered (simple component failure versus physical destruction of the unit as a whole)

1.3 TRADE STUDY CRITERIA

The trade study criteria used are divided in two groups; generic and trade unique.

1.3.1 Generic

The generic criteria are:

1. Cost (Development and Recurring)
2. Risk
3. Performance (Probability of error detection and recovery)
4. Standardization/commonality
5. Growth (Design extendability and technology insertion)
6. Impacts on user, operator, and subsystem designer

1.3.2 Trade Unique

The trade unique criteria are:

1. Availability/reliability of subsystems
2. Speed of recovery

3. Number of spares required
4. Ease of implementing and maintaining related software
5. Susceptibility to unit physical damage

1.4 APPLICABLE OPTIONS

1.1 Data Processing Hardware (Technology Options)

2.2.1 Fault Tolerance (Design Options)

1.5 ALTERNATIVES

The report on options for fault tolerance was organized into four sections. This format is continued into the summary of the trade study results in Section 3.0 (Reference Tables 1 to 4). These sections are:

- Error detection
- Hardware replication and reconfiguration
- Damage assessment
- Error recovery

Both the options report and this trade study treat fault tolerance by listing possible methods and the characteristics of those methods. (See Table 1 thru 4) Each subsystem may select an appropriate method from the list. In most cases there is no definite recommendation, as is usually required of a trade study. The reason is that requirements vary widely among subsystems, and often even within a single subsystem. It is not practical, for example, to recommend that every subsystem implement three active processors (for combined fault detection and isolation of the failed unit) just because the most critical applications may have such a need. Many subsystems are likely to be satisfied with running a single unit, possibly with another "system" processor monitoring basic fault status (running/stopped, power on/off, etc.). Therefore, Tables 1–4 have generally been arranged with the Decision Item column meaning "if you need . . .", followed by a brief description of the option and its characteristics, and ending with the Decision Rationale column indicating possible applications.

The alternatives below are discussed in more detail in the option report and are not repeated in this trade study.

Error Detection

- o Built-in test equipment (BITE)
- o Watchog timers
- o Parity and related techniques
- o Voting or external monitoring

Hardware Replication and Reconfiguraton

- o Standby sparing
- o Reconfigurable duplexing
- o Pair-and-spare
- o N-modular redundancy (NMR) voting
- o Reconfigurable voting
- o Reconfigurable multicomputers
- o Reconfigurable multiprocessors

Damage Assessment

- o Self test
- o Trouble reports correlation
- o Remote diagnostics

Error Recovery

- o Checkpoint/rollback
- o Audit trail
- o Information validation
- o Recovery block
- o N-version programming
- o Backup software
- o Compensation

2.0 METHODOLOGY

All of the techniques for fault tolerance use some form of redundancy to recover from errors.. Most of the techniques also use redundancy in the hardware or software to detect the presence of a fault. The list of alternatives in Section 1.5 is based on traditional methods, state-of-the-art systems, and research areas. The specific method to be used will depend on the particular needs of each subsystem. Because both volume and power are likely to be limited resources on the Space Station, the fundamental criterion may be that the smallest number of units should be selected which will satisfy the critical needs of the subsystem. Few subsystems on the Space Station should require the very rapid detection and recovery time provided by triple (or higher) redundant execution of programs. Critical subsystems which have reasonable recovery times (seconds to minutes) are likely to select duplex redundancy in some form because of its rapid detection of errors, and to use checkpoints to recover to a known state from which to continue operations. Subsystems in category 3 are expected to use only a single active unit, and to rely on internal hardware checks and monitoring by a "system" unit processor for basic run/stopped status as the error detection technique, followed by continuation from a checkpoint.

The general weighting of criteria in decreasing order of importance are:

1. Criticality of the subsystem
2. Required recovery time (the primary reason for triple redundancy)
3. Probability of detecting a fault (the reason for dual redundancy)
4. Probability of identifying the faulty unit
5. Ease and risk of writing detection and recovery software

3.0 RESULTS

3.1 SUMMARY

The results of the trade study are summarized in a set of decision matrix tables (Tables 1 through 4) in section 3.3 for the areas of (1) error detection, (2) hardware replication and reconfiguraton (two tables), (3) damage assessment, and (4) error recovery. The areas are not completely independent. For example, detection of faults by cross comparison of computed values is only applicable to replication which executes in two or more processors simultaneously, while detection of errors by built-in test equipment (BITE) is applicable in all cases.

3.2 RELATED TOPICS

3.2.1 Cross Comparison of Computed Results

The cross comparison of computed results is the basis of detecting faults in most of the redundant configurations. Experience has shown that this technique has a difficult practical problem in determining the level of acceptable difference in computed results before declaring a failure. If the design is such that results are not guaranteed to be identical, then the subsystem designer must somehow determine the level which both rejects widely differing faulty values and accepts widely differing good values. The appropriate level is usually found only in actual use, not during the design phase. A long term effort is required following the first operation, which can impact the life cycle cost.

If the design guarantees identical results, there is a difficult early design effort to define the technique and a long term effort to assure that these design assumptions continue to be satisfied as changes are implemented. The Space Shuttle experience shows (1) that identical results can be achieved by redundant computers but that development of software to assure identical results is significantly more difficult and costly than a single machine design, and (2) that every software change must be closely audited for potential effects on the entire redundant system. In addition, the designer has the problem of assuring that inputs to all processors are identical. This is achieved on Space Shuttle by closely synchronized input operations, with special hardware that allows one computer to request inputs and the other computers to listen to the response. A more general method is for each processor to read its own sensors, then exchange its inputs with all other processors to select a common value. Reference 1 shows that this design actually requires four processors and a double exchange to assure selection of the same value even for tolerance of a single fault. Any subsystem which aims for identical results should be aware that such a design is much more difficult than simplex software.

As a final observation on this topic, the mixing of different types of redundancy in a single processor is impractical at best. Even dual redundancy with tolerance checks will need to consider timing differences in setting the tolerances. If the loading of the processors is not the same (e.g., the subsystem is executing at a relatively high priority in one processor but at a relatively low priority in another processor), the subsystem is unlikely to be able to find any acceptable tolerance level. This problem has strong implications on the ability to combine subsystem processing as a strategy for total system fault tolerance.

3.2.2 Reliability and Sparing

Fault tolerance on Space Station has been specified as fail-operational, fail-safe, restorable (FO/FS/R) for critical systems. However, the reliability of the system is also of importance. One major contrast to Space Shuttle in this regard is the duration of a mission. Combined with the potentially larger number of required processors, the effect may be many expected failures between resupply cycles. The implication is either several onboard spares for replacement of failed units or the ability to repair such units on orbit (possibly by interchanging parts among the failed units).

Some reliability estimations show the effects of the larger number of units, the policy of common processors, and the longer interval of required operation. The Space Shuttle computers currently have a mean time between failures of about 5000 hours. A long misson may last 10 days (240) hours. Assuming that two computers must be operational at the end of mission for safety (one primary and one backup) and that all computers are running continuously, the probability of having less than two computers after 10 days is about 1 in 43,000.

One possible Space Station growth configuration, for example, has 21 processors (some embedded in work stations), with 17 potentially active and 4 off. A total of 9 processors are required before functions are lost. If needed, one processor of a redundant pair may be removed and used as a replacement for an otherwise failed function. If the mean time between failures is 10,000 hours and the resupply interval is 100 days (2400 hours), the probabilty of having fewer than 9 processors at resupply is about 1 in 20,000. However, there will be an average of 4 failures per flight.

If the spare units are not available for use in any subsystem (e.g., the spare navigation processor is only available for navigation and cannot replace a failed power subsystem processor), then the probabilty of loss of a dual redundant plus one spare triad is about 1 in 130 per triad, which is much worse than the 1 in 20,000 for the entire system with shared common spares for the same total number of units.

The primary message is that the requirement for FO/FS/R by itself does not assure a very high probability of retaining all functions. Either fewer processors may be used (with implications on less independence of development by subsystems), or several spare processors may be included in the logistics module at resupply time. The crew can expect to have to replace several processors between resupply cycles. The use of standard processors eases the problem of spares by allowing the option of moving (or reassigning through software) processors to other functions to compensate for failures.

3.3 DECISION MATRICES

Tables 1, 2, 3 and 4 summarize the primary results of this study. The contents of the tables are described below.

- o Table 1 (Error Detection) describes methods which can be used to detect errors/faults in individual orbital replacement units (ORUs). These methods will be the primary means of detecting errors in simplex systems and would supplement redundancy management in redundant systems. For systems in criticality category 3 these methods will provide the only means for detecting errors/faults.

- o Table 2 (Hardware Replication and Reconfiguration) presents an evaluation of how various levels and organizations of redundant ORUs can be used to archieve different levels of fault detection, fault isolation, and recovery times. Category 1 and 2 subsystems will have to be analyzed against the alternatives presented here and selections made based on individual subsystem requirements.

- o Table 3 (Damage Assessment) is related to isolating details related to a failure. In general these methods would not be of much value on orbit unless ORU are to be repaired there.

- o Table 4 (Error Recovery) describes the methods of recovery or restoring the operation of the software after a processor failure and methods of protecting against undetected software requirements, design or implementation errors.

4.0 CONCLUSIONS, RECOMMENDATIONS AND REMAINING ISSUES

The general conclusions are as follows:

1. Subsystems which are safety critical (where loss could cause immediate loss of life or damage to the Space Station) should select at least triple active redundancy (three computers active), because

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
Error detection technique	o Built-in test equipment(BITE)	o Continuous operation at circuit level, fast detection o Often inherent in equipment because of developmental and sell-off needs o Very useful for maintenance, by identifying failed assembly	o Additional hardware (typically 10%) increases weight, volume, power, and probability of fault		o Useful for fast detection of component level failures (maintenance)
	o Watchdog timers	o Traditional technique to detect major interface errors (e.g., no response) o Very little extra hardware	o Applicable to limited areas, such as box-to-box interface loss		o Useful for time-out checks at all levels
	o Parity and related techniques (cyclic redundancy checks, error correction codes)	o Continuous operation at circuit level, fast detection and possibly correction of errors o Becoming very attractive (ECC) for high density memories giving memory fault tolerance	o Additional hardware (typically an extra 6 bits for every 16 bits using ECC) increases weight, power, volume o Primary applicability to parallel or serial data transfers o Not useful for adders, logic, etc.		o Useful for direct data transfers (memories, parallel buses, serial buses)
	o Voting or external monitoring	o Applicable at unit level, and even at subsystem level o Includes simple external monitoring for periodic "I'm alive" status	o Some additional managment coordination across subsystems o Design (hardware and software) of voter/monitor		o See "Hardware Replication and Reconfiguration" for specific methods

Table 1
Decision Matrix: Fault Tolerance Trade Study -- Error Detection

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
100% availability, "instant" fault recovery	o TMR unit (or higher redundancy)	o Suppression of errors at component level o No slow-down or special software to handle errors	o Custom design of unit (expensive) o No help for physical damage to unit o Several active processors (power)	3	o No apparent application to Space Station
	o Pair-and-spare (two duplex units)	o Detection of errors at unit level in active pair o Recovery by switch to hot backup pair o Spatial distribution to guard against physical damage	o Design and analysis of acceptable tolerance levels, or assurance of identical results o Reliable switching method, if other than manual o Four active processors (power)	2	o Better utilization of units as quad-redundant, or TMR plus spare
	o TMR execution of simplex units	o Detection of errors at unit level o Identification of faulty unit by majority vote o Two good units continue duplex while off-line spare reconfigured as replacement in triad o Spatial distribution to guard against physical damage	o Design and analysis of acceptable tolerance levels, or assurance of identical results o Three active processors (power)	1	o Preferred. Good balance of fault detection, identification and recovery versus power
	o Duplex execution of simplex units	o Detection of errors at unit level o Minimal power of any redundant configuration o Spatial distribution to guard against physical damage	o Identification of failed unit may be difficult, less than 100% o Design and analysis of acceptable tolerance levels, or assurance of identical results	4	o Unlikely to meet need for 100% reliability

Table 2
Decision Matrix: Fault Tolerance Trade Study --- Hardware Replication and Reconfiguration

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
100% detection of faults, less than 100% isolation, "instant" recovery	o Duplex execution of simplex units, as "hot" backup ready to take control	o Minimal power of any redundant configuration o Spatial distribution o Identification of failed unit in most cases (above 80%) by BITE, parity, etc. o Rapid recovery whenever failed unit is correctly identified	o Identification of failed unit may be less than 100% o Design and analysis of acceptable tolerance levels, or assurance of identical results o Reliable switching method, if other than manual	1	o Widely used for fault tolerance of routine (component) failures
100% detection of faults, 100% isolation, seconds to minutes recovery time	o Duplex execution of simplex units, with "cold" backup loaded (off). Checkpoint restart.	o Minimal power of any redundant configuration o Bypasses fault by removing both active units at failure o Depending on application, checkpoints may not be required o Faulty unit diagnosed off-line, with good unit of pair available as spare o Spatial distribution	o Design and analysis of acceptable tolerance levels, or assurance of identical results o Writing of checkpoints requires nominal execution overhead o Must consider possibility of checkpoint being invalid because of subtle failures o Reliable method to start backup, if other than manual	1	o Suggested for use when assurance of correct fault identification outweights recovery time
Less than 100% detection of faults, seconds to minutes recovery time	o Simplex execution. Checkpoint restart. "Cold" backup	o Minimal power possible o Spatial distribution of backup o Depending on application, checkpoints may not be required	o Detection of faults by BITE, self-test, etc. (above 80%). o Writing of checkpoints requires nominal execution overhead o Must consider possiblity of checkpoint being invalid	1	o Suggested for non-critical applications

Table 2 (cont'd)
Decision Matrix: Fault Tolerance Trade Study -- Hardware Replication and Reconfiguration

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
Damage assessment technique	o Self test	o Classic technique of building into a unit the ability to check itself o Uses BITE plus internal diagnostics (e.g., wrap output back into an input) o Supplements BITE in isolating failed assembly for maintenance	o Demand only (not continuous), not very useful for transient faults o May be difficult to achieve extremely high coverage (above 95%), especially external interfaces	-	o Rapid identification of faulty unit, and possibly assembly, for a high percentage of cases
	o Trouble reports correlation (long term records of infrequent problems)	o Sometimes points to potential source of transient failures by correlation of numerous symptoms	o Cannot be automated o Manpower intensive, highly skilled o Requires single person to be very familiar with all failures o Requires extensive detail records		o Useful for unusually subtle transient failures with low rate of occurrence
	o Remote Diagnostics	o Emerging expert system application o Allows central point of control to command execution of diagnostics (e.g., self test), then use results to isolate assembly for replacement or repair	o New technology area (risk) o Highly specialized applications o Long-term cost reduction may not offset early expense on low volume production on Space Station		o Potential expert system

Table 3
Decision Matrix: Fault Tolerance Trade Study -- Damage Assessment

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
Recovery from processor failure	o Checkpoint / rollback	o Classic recovery technique o Contents specified by application	o Writing of checkpoints requires nominal execution overhead o Checkpoint may be invalid for some faults, requiring multiple copies and validation	1	o Applicable to most processes
	o Audit trail	o Extension of checkpoint method to include history of key transactions since checkpoint o Less volume of data than complete checkpoint (faster) o More current than full checkpoint	o Slower recovery than simple checkpoint (load checkpoint, then apply transactions from audit trail) o Two kinds of data to be validated	2	o Applicable when simple checkpoint is inadequate
Software recovery from software error	o Backup software	o Independent design, development, validation o Possibly subset of total capabilities, for safing	o Dual developments (expensive) o No protection against design or specification errors o Reliable method to select backup		
	o Recovery block (some acceptance criteria at end of a block, repeat using alternate method at failure)	o Attempt to include in the software additional software to protect against software errors o Intent is to minimize verification o Akin to BITE hardware	o Larger, slower, more complex programs o Not clear that recovery blocks are more than additional sources of errors		o Academic method at this time
	o N-version programming (compute several different ways, then select "best" answer at end of block)	o Same as recovery blocks o Speed advantage if computations can be in parallel (multiprocessor)	o Same as recovery blocks		o Academic method at this time

Table 4
Decision Matrix: Fault Tolerance Trade Study -- Error Recovery

of the abilty to detect the fault, isolate the faulty unit, and continue immediately with the remaining two units. There may be very few of these subsystems of this type on the Space Station.

2. Subsystems which are mission critical (where loss could affect the overall operation if not corrected in a few seconds or minutes) should select a dual redundant system with the two computers cross comparing results. At a miscomparison, the action will depend on the ability to identify the failed unit. If the unit is easily identified (e.g., one just quit running or is indicating BITE detected errors while the other appears to be good), control is given to the good unit while the failed unit is replaced. If the failed unit is not obvious, the best response may be to give control to a spare unit, using a checkpoint restart, until the failed unit can be isolated offline. Some possible needs for this option are docking operations and management of the entire orbital constellation.

3. Subsystems with low criticality (where loss for minutes or hours will not seriously affect operations) should select simplex execution. This option has the major advantages of minimizing power usage, and the practical advantage of much simpler software development and verification. Fault detection is primarily that provided by BITE, possibly augmented by a "system" process which monitors simple health of the unit.

4. Recovery techniques are highly dependent on the application. The most useful technique is expected to be the use of periodic checkpoints written by the application to a mass storage device.

5.0 REFERENCES

1. Reaching Agreement in the Presence of Faults, Journal of the ACM, Vol. 27, No. 2, April 1980, by M. Pease, R. Shoştak, and L. Lamport

SPACE QUALIFIED COMPUTERS TRADE STUDY

1.0 TRADE STUDY DEFINITION

1.1 Purpose of Trade Study

Space qualified data processing hardware represents a major element of the SSDS space segment and, therefore, has a pivotal role in supporting the development and growth of the Space Station, COP and POP. The specification, selection and procurement of this hardware must be comprehensively evaluated and defined to provide coherent solutions to the SSDS technical requirements while satisfying the prominent programmatic drivers. This trade study will address the key issues associated with this hardware to determine the preferred options and configurations.

1.2 Background

The SSDS architecture design is the process of translating the Task 1 defined SSDS functional and performance requirements into a specific system definition. It is anticipated that this definition will adopt a distributed processing approach since:

- the station itself has physically distributed modules and subsystems,
- processing loads may be too large to be efficiently supported by a centralized configuration,
- network technologies with adequate data rates to support SSP applications are currently being defined/developed and will be available for IOC,
- a distributed approach provides an inherently more damage tolerant configuration,
- a modularity is provided that supports technology insertion, an orderly growth, and concepts of standardization/commonality.

Preliminary concepts of the Space Station Data Management system have espoused a distributed (LAN) architecture and have also defined a subsystem (standard) data processor (SDP) dedicated or assigned to each of the identified onboard subsystems and separable functions of the DMS. These SDP's would be a single configuration, physically identical, and qualified to the same environmental levels, thus providing absolute interchangeability. This approach is representative of the "commonality" concept intended to provide significant program acquisition and operational savings through reduced design, development, and test efforts, lower maintenance and tooling costs, fewer spares requirements and a narrower expertise base. On closer inspection, however, issues surface involving specific SDP configuration, applicability, environmental qualification, operability, and growth, to suggest that the above homogeneous concept may be less than realistic. The intent of this trade study package is to identify and resolve these issues.

A fundamental issue to be initially addressed is the use of homogeneous vs heterogeneous hardware. The homogeneous concept, as noted earlier, utilizes only a common processor as noted in option 1 below. The heterogeneous approach provides the three additional options listed.

- Option 1 - selection of a common processor.
- Option 2 - selection of an instruction set architecture without specifying the physical implementation.
- Option 3 - relaxation of the commonality concept to allow selection from a small set of general purpose and special purpose processors.
- Option 4 - total selection freedom.

Option 2 is an attempt to capitalize on the software development and maintenance benefits of the fixed istruction set without confining designers to specific hardware solutions. All technology upgrades are replacement candidates with this option.

Option 3 attempts to alleviate the blanket hardware solution approach of Option 1 by providing a set of common processors. Such a set might include an AI LISP machine and a "backend" data base machine in addition to the general purpose SDP.

Option 4 allows total design freedom and would rely on a robust SSDS distributed operating system to maintain a functional and efficient system operation.

At this generically high level of discussion, only programmatic arguments are exposed, however they are sufficient to derive an initial disposition of these options. In reviewing the complete set of evaluation criteria, provided in Section 1.4, the only parameter of consequence is that of "maintainability" which involves the manpower, tools, expertise, and spares requirements. Option 1 tends to minimize these maintenance requirements while Options 2 and 4 clearly increase them by at least an order of magnitude. The additional burdens generated by Options 2 and 4 are judged to be too severe, therefore, these options are not considered feasible and will not be further addressed. Option 3 remains viable and is discussed as Trade Study No. 2.

Regardless of the outcome of the final IOC configuration, it is anticipated that the growth configurations will tend to be increasingly heterogeneous because:

- significant cost savings can be realized through continued use of technically acceptable hardware,

- applications may tend to diverge in terms of DP requirements, particularly with the increasing momentum of Artificial Intelligence.

In addressing the SDP, one of the more significant issues is the utilization of formal Military/DoD standards. The implication is that these standards provide a more stable product with broad commercial support in both hardware and software areas. The alternative commercial products, in contrast, are perceived to be "moving targets" with less stability and decreasing long term support. The MIL-STD-1750A ISA standard is currently widely supported and provides the benefit of direct software portability, however this architecture is not current and is further limited by a 16-bit format and a direct addressability of 1 Mword. Commercially available configurations are more technically attractive but may present a potential liability with respect to long term hardware and software support; 16-bit/32-bit format decisions are closely coupled to this issue since the 1750A is the only processor standard being currently supported.

As indicated earlier, blanket utilization of a "common" SDP will not provide an optimal or even totally satisfactory solution to all applications. As discussed, a preferred option may include use of common special purpose architectures, i.e., LISP machines for artificial intelligence applications, or back end data base machines for data base management functions in conjunction with an SDP.

Environment qualification levels are also considered to be an issue, particularly since the POP radiation environment is considerably more severe than that of the Space Station and COP. It may be more cost effective to utilize a different configuration for the POP with respect to radiation qualification levels or different components.

Finally, the SDP is generally perceived as a stand-alone, black box unit, and is addressed from a commonality point at that level. The commercial market is moving toward general and special purpose single board computers, memories and peripheral controllers. There are significant architectural and operational implications to redirecting the commonality control point to a circuit card format with a corresponding backplane.

An initial activity for this trade study has been the development of a preliminary and generic set of SDP performance requirements in terms of I/O rates, memory sizing requirements, and throughput. These requirements were developed from a survey of the functional requirements provided in the study data base. The resulting envelope, shown in Figure 1.2-1, provided an initial target only for the purpose of conducting this trade study. The envelope provided is actually an expansion of the generated requirements to provide typical (100%) growth margins for memory and throughput.

1.3 Issues

The following paragraphs present the issues to be addressed in this study package.

1.3.1 Trade 1 - Standard Instruction Set Architecture (ISA) vs Commercial ISA

The primary benefit of establishing an instruction set architecture as the common element is that of software portability. The implications are substantial for a program of the magnitude of the Space Station because of replicated software modules and programs, and the potential of reusing software developed for other programs. Will a Military/DoD standard ISA or a popular commercial ISA provide the better approach?

1.3.2 Trade 2 - Special Applications vs SDP

The blanket solution of an SDP may satisfy a large number of applications provided the SDP design/performance requirements are judiciously selected to provide an adequate envelope. Some applications, however, may either drive the SDP envelope to unreasonable limits or may be significantly compromised in their own functional and performance requirements. In such cases, special purpose machines such as LISP machines, or data base machines, may provide more effective solutions. Does this limited heterogeneous mix of processors provide a better approach than the homogeneous sets?

ON BOARD FUNCTIONS (FUNCTION NUMBER)	ANALYZED PERFORMANCE REQUIREMENTS					DERIVED PERFORMANCE ENVELOPE				
	INPUT/OUTPUT		MEMORY		CPU	INPUT/OUTPUT		MEMORY		CPU
	INPUT BYTES/SEC	OUTPUT BYTES/SEC	PROGRAM (BYTES)	OPERAND (BYTES)	THRU'PUT (KIPS)	INPUT BYTES/SEC	OUTPUT BYTES/SEC	PGM (BYTES)	OPERAND (BYTES)	THRU'PUT (MIPS)
o CONTROLS/NAVIGATION (4.1.1/4.1.3)	23.34	5.95	286.6	101.9	452.97					
o GUIDANCE/TRAFFIC (4.1.2/4.1.4)	0.33	0.23	145	44.5	17.77					
						>>> 256K-500K	256-500K	500K	400K	1.0 - 2.0
o ECLSS (4.2.4)	7.71	7.68	85	32	0.26					
o D/BASE MGMT (5.1.1)	225.11	225	294	200	103.01					

Figure 1.2-1.

1.3.3 Trade 3 – Radiation Tolerance Qualification

The radiation environment of the POP is relatively severe in comparison to that of the Space Station and COP. Since the overall cost of the high radiation tolerance components and the associate qualification effort is high, is it more effective to provide a differing radiation tolerant SDP configuration for the COP?

1.3.4 Trade 4 – Fault Tolerance Configuration Control

Clearly, fault tolerance will be a fundamental requirement for the onboard data processing, however concepts of its implementation are not as clear. One of the key issues in this area is subsystem/SDP fault tolerance, i.e., should the SDP include fault tolerance mechanisms to support detection, reconfiguration and recovery, or should the SSDS control these operations?

1.3.5 Commonality Control Point

The generic processor has been generally depicted as a box level element with commonality control applied at that level. An option of the current and developing technologies, however, is to provide high performance single board computers (SBC) that support a specific back plane. This approach would add significant flexibilities to the overall architecture while providing a number of programmatic benefits. Is it a preferred option to implement SDP/module commonality at a "standard" circuit card compatible with a defined backplane? This issue will be addressed purely in discussion form.

1.4 Trade Study Criteria

This section provides a complete dictionary of the parametric criteria used in this trade study. The criteria set selected for each trade-off activity is provided in Figure 1.4-1. Also shown in the Figure are the assigned parameter weights, which, as discussed in Section 2.0 Methodology, provide an assessment of the relative impact of each parameter to the project success.

	Trade 1 Std vs Comm'l ISA	Trade 2 Spec. Purp. Arch.	Trade 3 Radiation Qual	Trade 4 Fault Tolerance
Cost				
- Non-recurring	9	9	10	9
- Recurring	9	9	10	9
Devel. Risk	8	3	10	8
Performance				30
- Throughput	9	15	10	
- Addressability	9	10	0	
- Accuracy	7	2	0	
Reliability	4	3	8	5
Maintainability	9	12	10	0
Physicals				
- Size	0	1	3	8
- Weight	0	1	3	8
- Power	0	2	4	8
Env. Tolerance				
- Vib/Shock	2	2	0	0
- Thermal	2	2	0	0
- Radiation	7	5	0	0
Vendor Support	10	7	10	0
S/W Devel. Support	10	7	8	0
Growth				
- Extendability	0	5	7	7
- Insertability	5	5	7	8
Weighting Totals:	100	100	100	100

Figure 1.4-1. Trade Study Criteria/Weighting

1.4.1 Criteria Dictionary

- Option Costs – consists of both non–recurrent (development) and recurrent costs.

  a. Non–recurrent: includes basic development and qualification costs.

  b. Recurrent: includes not only the basic unit production costs but also:

     - requirements for special/more expensive hardware items,
     - special environmental requirements,
     - special reliability screening,

- Development Risk – Addresses:

  a. Difficulty of implementation and,

  b. Difficulty of achieving design requirements.

- Processor Performance – Addresses throughput, addressability, and accuracy as defined below:

  a. This measure has less meaning with the variability of instruction functionality. For this study, the throughput has been normalized by estimation to the Digital Avionics Integration System (DAIS) instruction mix.

  b. Addressability: size of directly addressable memory space.

  c. Accuracy: number of significant figures in processor floating point formats.

- Reliability:

  Projected operational failure rates of options.

- Physicals:

  a. Size, volume
  b. Weight
  c. Power dissipation

- Environmental Tolerance:

  a. Vibration/Shock - assessment of ruggedness of option.
  b. Thermal - assessment of option stability over thermal range.
  c. Radiation - assessment of tolerance to total dose radiation and SEU.

- Fault/Damage Tolerance:

  Assessment of the autonomous fault/damage tolerance.

- Maintainability/Repairability:

  Ease of maintenance/repair with respect to manpower, tools, expertise, replacement parts availability, replacement parts costs and projected down-time.

- Vendor Support:

  Assessment of long term hardware support by the vendor or second sources; addresses not only hardware (end item, module), deliveries, by vendor or second sources, but also any special screening and/or repair support.

- Software Environment Support:

  Deals with the general vendor and after market software support for the option in terms of HOL's, compilers, and application software that can be re-used by the SSP.

- Growth Accommodation:

  Consists of two elements, extendability, and insertability defined as follows:

  a. Extendability is the ability to add modules to an option to provide more capability/capacity.
  b. Insertability is the concept of direct (minimal impact) replacement of an option with an improved or technologically upgraded element.

2.0 Trade Study Methodology

For each of the trade areas, the following methodology has been applied.

1) Fully characterize the options: Each option will be characterized as fully as possible to allow a fine grained assessment corresponding to each parameter of the criteria.

2) Select and appropriate set of evaluation parameters: This set has been taken from the total set listed in Section 1.3 and is tailored for the specific trade activity.

3) Provide weighting factors for each evaluation parameter: A weighting factor has been assigned to each parameter of the criteria set based on its relative impact to the project success. Cost, for example, is a relatively high impact parameter and will be assigned a higher percentage weight. Development risk will also carry a higher weight since acquisition phase problems generally result in significant cost and/or performance penalties. Reliability, normally a high impact item, is less so on the Space Station because of the onboard maintainability and therefore carries a correspondingly lower weighting.

4) Provide a numerical assessment for each option: A numerical assignment (0-10) will be entered in each option column, corresponding to each parameter of the criteria. This assignment provides a relative estimate of

the suitability or effectiveness of the option based strictly on that parameter. A "5" indicates an average assessment, a "0" indicates a total deficiency. Note that inverse parameters, such as risk are inversely rated, i.e., higher costs and risks generate lower ratings.

5) Score and rank the options: The parameter assignment times its weighting provides the option score for that element of criteria. The preferred option is generally identified by the largest criteria score sum. The exception is when an option has a rating of less than "2" for any parameter that has a weighting of more than '5'; that option is disqualified from consideration.

6) Perform sensitivity analysis: An analysis will be performed to identify the key decision drivers.

7) Re-Evaluate individual trade activities: Each trade study will be evaluated to determine whether the results are reasonable and expected, to resolve any perceived inconsistencies, and to eliminate potential coupling of dependent issues.

3.0 TRADE STUDY DISCUSSION AND RESULTS

3.1 Standardization vs Commercial Instruction Set Architectures

3.1.1 Discussion

Given that a homogeneous processor network is to be implemented, and that a specific instruction set is to be implemented for the overall software benefits, this trade activity addresses whether that instruction set architecture should be a formal Military/DoD standard or a popular commercial unit.

Military/DoD standards have been invoked to specify requirements to meet space/weapons systems needs, stabilize specific configurations thereby promoting hardware interchangeability and software portability, significant benefits, provided that the standards are widely supported and therefore have a projected longevity.

There are currently two DoD processor standards for consideration: the MIL-STD-1750A 16-bit Instruction Set Architecture (ISA), and the MIL-STD-1862B 32-bit (ISA). Industry support for the 1750A specification is broad and deep representing significant vendor development investments in hardware and software. A growing number of technology implementations are in work as tabulated in Options paragraph 1.3.3, including VHSIC. The software portability provided by this standard would be of significant benefit to the SSP not only for the concepts of re-useable programs, but also because of the effective transparency of hardware growth and technology updates.

The 1862B specification appears to be currently inactive because of a lengthy and complex instruction set; there are no projections for its resurrection, therefore it will not be considered as an option in this study.

The commercial market in this tradeoff has been represented by the popular Motorola MC68000 16-bit and the MC68020 32-bit microprocessors. Note that the MC68000 is categorized as a 16-bit unit based on its 16-bit data paths and ALU's.

The criteria parameters are discussed briefly in the following paragraphs.

- Cost

The relative development and recurring costs for the three option CPU's are established by the following:

- Commercial vendor specification and application documentation is generally more comprehensive and the applications are broader.
- The 1750A includes floating point data formats, considered to be a general requirement; the MC68020 must use a true co-processor, the MC68000 must use a co-processor but as a peripheral with attendant performance penalties.

- Performance

a) Throughput: The current 1750A performance is in the 0.6 MIP to 1 MIP range; the 1750A VHSIC implementation will provide a 3 MIP to 5 MIP range. The MC68000 performance is approximately 0.5 MIP while the MC68020 will execute at approximately 2 MIPS.

b) Addressability: The 1750A is limited by specification to 1 Mbyte which is the probable minimum for SS onboard applications. It is anticipated, however, that this limit will be increased to 8 Mbytes at the next specification change. The MC68000 has a direct addressability of 16 Mbytes while the MC68020 has the full direct addressability of 4 Gbytes. If necessary, the 1750A and MC68000 based systems could utilize additional hardware, i.e., paging or segment registers, to further expand their addressing capability.

c) Accuracy: Both commercial units have a double precision integer format, and would use a co-processor for floating point formats. The 1750A has a 32-bit and (extended) 48-bit floating point format, however, the 48-bit format has a substantial processing time penalty.

- Environmental Tolerance

There are no identified discriminants with respect to thermal or mechanical environments. The 1750A implementation in CMOS/SOS or VHSIC are expected to exhibit total dose radiation tolerances to better than 10^6 rads(Si) while the commercial units have a projected tolerance of considerably less. The 68000 utilizes NMOS technology which has characteristically low total dose tolerance in the range of 1K-10K rads (Si). The 68020 utilizes bulk CMOS technology which has a higher tolerance potential but must be implemented with specific design/processing rules to achieve tolerance levels of any significance. Commercial vendors are not inclined to invest the required resources for such a low volume market. The 1750A must therefore be assessed as superior for this parameter.

- Vendor Support

The commercial units may have an edge in the CPU hardware area, since there is currently second sourcing. It is anticipated though not guaranteed that VHSIC 1750A units will also be second sourced.

- Software Environment Support

The 1750A must be awarded a significant edge in the area of software support since the momentum for its applicability is building and it is the target machine for much of the HOL/compiler development. Although the 68000 also has wide support, including Ada, the longevity of this support must be in question as the commercial market moves on the next evolutionary unit.

3.1.2 Results

As shown in Table 3.1-1, the Standard processor is the preferred option. Sensitivity analysis shows radiation tolerance, vendor support, software environment support and insertability to be the significant factors.

3.2 Special Purpose vs Standard Architectures

3.2.1 Background

Clearly, a fixed configuration, general purpose processor cannot provide an optimum solution for all applications but will, with judicious selection, support a large range of processing requirements. Some applications, however, may be better served by more specialized machines. Artificial intelligence (LISP) programs, for example, may be executed by the SDP but at a significantly speed penalty compared to the current "LISP" machines.

The data base management function with its multiple user, minimal access time requirements, provides another example where application of the SDP may be marginal compared to special data base machines or "back end" hardware. These two areas, AI and D/Base management, will be traded against the SDP in this section.

TABLE 3.1 - 1

TRADE STUDY TITLE: STANDARD VS COMMERCIAL ISA PROCESSORS

CRITERIA	WEIGHT	OPTION 1: STANDARD EVALUATION	TOTAL	OPTION 2: 16-BIT COMM'L EVALUATION	TOTAL	OPTION 3: 32-BIT COMM'L EVALUATION	TOTAL
COST							
NON-RECURRING:	9	5	45	7	63	7	63
RECURRING:	9	6	54	7	63	7	63
DEVEL. RISK:	8	7	56	7	56	7	56
PERFORMANCE			0				
THROUGHPUT:	9	7	63	5	45	9	81
ACCURACY:	7	6	42	5	35	8	56
ADDRESSABILITY:	9	6	54	8	72	10	90
RELIABILITY:	4	7	28	7	28	7	28
PHYSICALS							
SIZE:	0		0		0		0
WEIGHT:	0		0		0		0
POWER:	0		0		0		0
ENV TOLERANCE							
VIB/SHOCK:	2	7	14	7	14	7	14
THERMAL:	2	7	14	7	14	7	14
RADIATION:	7	9	63	2	14	3	21
MAINTAINABILITY	9	7	63	7	63	7	63
FAULT/DAMAGE TOL.	0		0		0		0
VENDOR SUPPORT:	10	9	90	7	70	7	70
S/W ENV'T SUPPORT:	10	10	100	7	70	7	70
GROWTH ACCOM.							
EXTENDABILITY:	0		0		0		0
INSERTABILITY:	5	8	40	5	25	5	25
TOTALS:	100		726		632		714

3.2.2 LISP Machine vs SDP

3.2.2.1 Discussion

The branch of AI utilized on the Space Station is anticipated to be the Knowledge (Rule) Based Expert System. The estimated generic requirements for Space Station expert system applications are: 2 MIP – 3 MIPS, floating point formats, 2+ Mbytes of internal memory and high speed disk capability, and a high speed I/O. Application of the MIL-STD-1750 class of processor, even the 3 MIP – 5 MIP VHSIC implementation, has an apparently limited utility for this application even for today's primitive applications. Special purpose LISP machines for such applications are currently available from Xerox, Symbolics, LMI, and TI, however. In addition, Symbolics is actively pursuing a flight qualified LISP machine and TI has a Navy contract to develop a 2-micron CMOS processor LISP machine that will perform 10 times faster than the current units. It is estimated that the current LISP designed units with their tailored architectures and micro-coding would out perform the 1750 by a factor of up to 6 to 8 times for true (high level) expert systems applications.

The criteria selected for this trade is discussed in the following paragraphs.

- Cost

The cost of a ruggedized LISP machine including component reliability upgrade will be comparable to the ruggedized 1750A. Recurring costs should therefore be similar but the additional LISP development and qualification costs are applicable to that option.

- Development Risk

Development risk is a low impact issue since acceptable configurations of LISP units are projected to be available.

- Performance

Accuracy of the 1750A will be adequate for the expert systems applications, however its addressability, at 1 Mbyte, is marginal and may remain so even with the anticipated increase to 8 Mbyte at the next specification change. And, although the 3 MIP to 5 MIP VHSIC 1750 may appear to have sufficient throughput, it is estimated that the 1750 will still operate expert system software a minimum of 6 times slower than the corresponding LISP unit.

- Reliability

The commercial vs standard reliability assessment provided in the initial trade persists here.

- Maintainability

Addition of a second "common" (LISP) configuration to the SSDS will add to the program burden in terms of additional tooling, spares requirements, etc.

- Physicals

Circuit card oriented LISP machines are now becoming available, such that the physicals of the LISP and the near term 1750A units will be comparable; similarly, there will be no significant discriminant between the VHSIC 1750 implementation and the TI 2-micron LISP unit.

- Environmental Tolerance

The projected attributes of the LISP units, particularly with ongoing development, shows no particular concern even in the area of radiation tolerance.

- Vendor Support

Here, as with the prior trade study, the commercial unit tends to be perceived as a moving target with potentially less than desirable long term support;

however, most commercial products provide upward compatibility to avoid loss of existing software.

- S/W Environment Support

With appropriate selection of the specific LISP configuration the software support should closely parallel that of the SDP.

- Growth Accommodation

There are no discriminants in this area.

3.2.2.2 Results

As shown in Table 3.2-1, the LISP machine is the preferred option. Sensitivity analysis shows performance to be the key evaluation factor.

3.2.3 SDP vs D/Base Machine

3.2.3.1 Discussion

The function of data base management is to accept, provide access to and maintain accurate copies of telemetry and engineering data, application programs, procedures and schedules within the on-board secondary (mass) data storage. This function includes access (authorization) control, directory maintenance, file management, plus the compare, merge, and sort operations for the generation of appropriate responses to subsystem or work-station initiated transactions. The data base system must have adequate data transfer rates and data access times to provide efficient transaction response times.

Preliminary planning has assigned Data Base Management to an SDP, however, a qualified version of a commercially available data base machine or a back-end data base processors may provide a better solution. This section will examine this issue.

TABLE 3.2 - 1

TRADE STUDY TITLE: SDP VS SPECIAL PURPOSE AI (LISP) MACHINE

CRITERIA	WEIGHT	OPTION 1: SDP (1750A) EVALUATION	OPTION 1: SDP (1750A) TOTAL	OPTION 2: LISP MACHINE EVALUATION	OPTION 2: LISP MACHINE TOTAL	OPTION 3: EVALUATION	OPTION 3: TOTAL
COST							
NON-RECURRING:	9	7	63	3	27		
RECURRING:	9	7	63	7	63		
DEVEL. RISK:	3	7	21	3	9		
PERFORMANCE							
THROUGHPUT:	15	3	45	9	135		
ACCURACY:	2	7	14	7	14		
ADDRESSABILITY:	10	3	30	9	90		
RELIABILITY:	3	7	21	7	21		
PHYSICALS							
SIZE:	1	7	7	7	7		
WEIGHT:	1	7	7	7	7		
POWER:	2	7	14	7	14		
ENV TOLERANCE							
VIB/SHOCK:	2	7	14	7	14		
THERMAL:	2	7	14	7	14		
RADIATION:	5	7	35	7	35		
MAINTAINABILITY	12	7	84	3	36		
FAULT/DAMAGE TOL.	0	0	0	0	0		
VENDOR SUPPORT:	7	8	56	7	49		
S/W ENV'T SUPPORT:	7	9	63	7	49		
GROWTH ACCOM.							
EXTENDABILITY:	5	5	25	5	25		
INSERTABILITY:	5	7	35	6	30		
TOTALS:	100		611		639		0

The currently defined design characteristics for the on-board DBMS mass store are:

- 256 Mbyte capacity
- 10 Mbit/sec transfer rate
- 40 millisecond access time
- space qualified

Since the non-recurrent space qualification effort for any special purpose hardware, and the effect of its use on maintainability, i.e. non-commonality, must all be offset by the resulting increased performance, then the performance requirements for IOC and growth are necessarily the key evaluation drivers.

No query/response technical requirements have been established other than to state that response times should be consistent with commercial data base systems. Response times, however, are a function of the density and complexity of the requests. The commercial machines provide faster query service and excel within a multiuser high demand environment; a general purpose SDP class unit in the same environment would be intolerably slow. The Britton-Lee unit, as noted in the Data Processing Options paper, serves up to 64 hosts, utilizing a 10 MIP accelerator for extremely fast brute force search operations. No data base scenarios have been provided for the Space Station detailing timelines and request types however a relatively infrequent query environment is anticipated at least for IOC. In this environment, special purpose machines are still faster but the delay will be inconsequential to the query source. A simple analysis indicates that a crude search operation on a file involving as much as 100Kbytes, could be performed in less than two seconds utilizing an SDP.

It must also be noted that software may be more significant than hardware in the area of data base management. Sophisticated software can provide a depth of indexing such that the search operations can be accelerated by an order of magnitude.

3.2.3.2 Results

It is concluded from this examination that special purpose hardware will not be required for the data base management function for IOC. The key drivers are:

1) the increased development costs required to ruggedize a special purpose unit, and,

2) the inconsequential query response time reduction that would result from the addition of the special purpose unit.

This issue must be re-evaluated for growth phases when their query/request environment is better defined.

3.3 Radiation Qualification Levels

3.3.1 Background

As indicated in Options section 3.5.1, the accumulative radiation exposure in the Space Station and COP low inclination, low earth orbits is minimal because of the natural shielding of the earth's magnetic field. The POP, in contrast, passes through the "unshielded" polar regions during approximately 30% of its orbit and thus is exposed to significantly higher radiation levels.

Although radiation is potentially a key driver to the procurement activity, there is also considerable programmatic motivation to enforce standardization/commonality for the benefits of reduced spares requirements and narrower hardware expertise requirements. In this regard, the options, previously identified in the Procurement Activity white paper, are to:

1) Qualify the SDP to the higher POP 10 year total dose radiation levels and use the resulting configuration for all SDP applications

2) Provide a unique POP SDP configuration that alone has the required radiation tolerance, and,

3) Periodically replace the POP hardware following intervals consistent with its qualified tolerance.

It is initially noted that in addition to total dose radiation tolerance, the single event upset (SEU) phenomenon, must be addressed for all space hardware to minimize potentially catastrophic latch-up effects are minimal. Option 1, however, involves only the total dose radiation effects and addresses the net effort to outfit the entire SDP fleet with components qualified to the POP tolerance requirements. Based on the current technology realities, this effort to provide CPU, memory, and I/O components that are radiation tolerant is significant. The component costs, and qualification costs will be very high, and will be recurrent involving a larger number of manufacturing lots because of the utilization of this "common" radiation qualified SDP for all applications.

Option 2 addresses the effort of developing a differing configuration for the POP SDP in order to meet its radiation tolerance requirements. This option can be further decomposed to characterize this POP configuration as:

2a) identical except for component qualification to the higher levels, or
2b) different components and design

Option 3 addresses the potential of periodic replacement of the POP hardware based on a demonstrated radiation tolerance level and monitoring dose rate during change-out intervals.

This trade was performed in two stages; first the preferred approach of options 2a, and 2b was determined, then this preferred option was traded against options 1 and 3.

3.3.2 Unique POP SDP Configuration Trade Effort

3.3.2.1 Discussion

Option 2a involves the effort of qualifying the components of "common" SDP to the higher levels of the POP environment. The net gain of this option is that the more expensive parts from the qualified production lots would be utilized only on the POP SDP's. A unique POP would therefore be generated with its own 'spares' requirements, although it is recognized that these spares could be used in Station and COP applications if required. This option also includes the potential of selectively shielding components that cannot demonstrate the requisite radiation hardness.

Option 2b encounters significant development costs and qualification costs of a fully unique configuration.

The criteria for this trade are discussed briefly in the following paragraphs

- Cost

Option 2b imposes the cost of the unique configuration development.

- Development Risk

Program development risks are increased for the new development of option 2b. The risks of option 1 may be more than minimal, however, the capability of selective shielding for components that cannot meet full criteria reduces the overall option risk.

- Performance

Discriminants are identifiable only in the area of throughput which may be impacted in option 2b with its differing (higher radiation tolerant) components.

- Reliability

The component count of option 2b will most likely be higher which will tend to reduce its reliability.

- Maintainability

Both options require unique configurations and unique spares; however, since the 2a option will be physically replicate, except for possible component shielding, it has an edge in repairability.

- Physicals

Option 2b may in fact require a higher component count, with a resultant impact on its physicals; size, weight and power.

- Vendor support

In terms of the hardware support, option 2b will have a lower rating due to the lower production quantities which generally translates to reduced leverage on vendors.

- S/W Environment Support

No discriminants have been identified.

- Growth Accommodation

No discriminants identified.

3.3.2.2 Results

As shown in Figure 3.3 - 1, option 1, the radiation qualification of all parts is the preferred approach. Sensitivity analysis shows the significant driver in this evaluation to be development cost, develop risk and to a lesser extent, maintainability. As discussed in the criteria, although this preferred approach uses the same parts, a unique POP configuration results.

TABLE 3.3 - 1

TRADE STUDY TITLE: UNIQUE POP SDP OPTIONS

CRITERIA	WEIGHT	OPTION 1: QUAL PARTS EVALUATION	TOTAL	OPTION 2: DIFF PARTS EVALUATION	TOTAL	OPTION 3: EVALUATION	TOTAL
COST							
NON-RECURRING:	10	8	80	3	30		0
RECURRING:	10	7	70	7	70		0
DEVEL. RISK:	10	6	60	4	40		0
PERFORMANCE							
THROUGHPUT:	10	7	70	6	60		0
ACCURACY:	0		0		0		0
ADDRESSABILITY:	0		0		0		0
RELIABILITY:	8	7	56	6	48		0
PHYSICALS							
SIZE:	3	7	21	6	18		0
WEIGHT:	3	7	21	6	18		0
POWER:	4	7	28	6	24		0
ENV TOLERANCE							
VIB/SHOCK:	0		0		0		0
THERMAL:	0		0		0		0
RADIATION:	0		0		0		0
MAINTAINABILITY	10	5	50	4	40		0
FAULT/DAMAGE TOL.	0		0		0		0
VENDOR SUPPORT:	10	7	70	6	60		0
S/W ENV'T SUPPORT:	8	7	56	7	56		0
GROWTH ACCOM.			0				
EXTENDABILITY:	7	7	49	6	42		0
INSERTABILITY:	7	7	49	7	49		0
TOTALS:	100		680		555		0

3.3.3 Radiation Environment Options

3.3.3.1 Discussion

This trade effort determined the preferred approach of the previously identified option 1 and option 3 listed below with the identified preferred approach from Section 3.3.2.

Option 1 - Perform full radiation qualification of all SDP application.

Option 2 - Utilize the above qualified parts only on the POP SDP applications, with the potential for selective component shielding.

Option 3 - Periodically replace the POP SDP's.

The criteria for this trade is discussed briefly in the following paragraphs. Note that only Cost and Maintainability are applicable.

- Cost

All three options require component radiation qualification. The net cost savings would be associated only with the reduced component costs of option 2a. Option 3 suffers significant recurrent costs of the periodic replacement activity even though possibly tempered by other servicing requirements.

- Maintainability

Option 2a requires a unique POP SDP configuration and is therefore less favorable.

3.3.3.2 Results

As shown in Table 3.3 - 2, qualification of all (fleet) components is the preferred option. Sensitivity analysis shows that recurring cost is the significant driver for this selection.

TABLE 3.3 - 2

TRADE STUDY TITLE: RADIATION QUALIFICATION OPTIONS

CRITERIA	WEIGHT	OPTION 1: QUAL ALL PARTS EVALUATION	TOTAL	OPTION 2: NEW CONFIG EVALUATION	TOTAL	OPTION 3: REPLACE EVALUATION	TOTAL
COST							
NON-RECURRING:	33	7	231	3	99	7	231
RECURRING:	34	7	238	6	204	3	102
MAINTAINABILITY	33	10	330	3	99	10	330
TOTALS:	100		799		402		663

3.4 Fault Tolerance

3.4.1 Background

Fault Tolerance will be a fundamental attribute of the Space Station, to support the 'fail operational, fail safe, restorable' requirements of the RFP particularly in support of the "build-up" and potential man-tended scenarios of the Station.

Fault tolerance techniques are generally distributed across several hardware levels, i.e. module, processor, and sub-system hardware levels with control of reconfiguration and recovery, generally residing at the level above the failure point. Management of sub-system fault tolerance could therefore reside in the SSDS Configuration Management/Operating System regardless of whether the SDP's are dedicated or assigned. There is a some consideration, however, implied by the NASA Reference Configuration, that the sub-systems should be fully autonomous with little reliance on the SSDS for anything other than data transfer and time references. This suggests that the sub-system fault tolerance implementation should be totally imbedded within, and controlled by the sub-system. The final resolution may impact the design requirements of the SDP to include specific Fault Tolerance features in the form of replicated modules for to support failure detection, reconfiguration and recovery. The issue addressed in this section is whether the SDP should: 1) include these additional features to support a more autonomous approach; or 2) rely on the SSDS operating systems to provide the management.

Discussion of the criteria for this trade effort is provided in the following paragraphs.

- Cost

The cost of additional features both in initial development and recurrent costs adds significantly to option 1. This differential is somewhat offset by the added complexities to the SSDS Configuration Management function, however, the evaluation still favors option 2.

- Development risk

Again, the necessity for the added SDP development scope downgrades option 1.

- Performance

For this trade, performance is interpreted as the period of latency between the failure and the restart. This evaluation favors option 1 because of the perceived reduced response time between fault detection and restart, particularly if 'pair and a spare F/T techniques' have been implemented. In many applications a relatively long latency may be acceptable however, because of commonality goals, the evaluation must align with the most stringent needs.

- Growth

No discriminants have been identified for either option.

3.4.2 Results

As shown in Table 3.4-1, option 2, control of fault tolerance by the SSDS is preferred. Sensitivity analysis shows the key drivers to be recurring costs, and growth parameters.

3.5 Imbedded vs Stand Alone SDP Options.

3.5.1 Background

As indicated in earlier discussions, there is considerable programmatic impetus toward standardization and commonality, however, these concepts have not been fully explored for the SDP with respect to potential control points. The SDP has generally been discussed as a complete, stand-alone unit. With the growing availability, and projected increases in single board processors with both general and special purpose architectures, it appears viable to consider a specific circuit card/back plane format for the SDP and expanded processing requirements.

TABLE 3.4 - 1

TRADE STUDY TITLE: FAULT TOLERANCE

CRITERIA	WEIGHT	OPTION 1: AUTON. S/S EVALUATION	TOTAL	OPTION 2: SSOS O/S EVALUATION	TOTAL	OPTION 3: EVALUATION	TOTAL
COST							
NON-RECURRING:	9	7	63	5	45		
RECURRING:	9	4	36	9	81		
DEVEL. RISK:	8	5	40	7	56		
PERFORMANCE							
DETECTION	10	10	100	6	60		
RECONFIGURATION	10	9	90	7	70		
RECOVERY	10	8	80	6	60		
RELIABILITY:	5	6	30	7	35		
PHYSICALS							
SIZE:	8	5	40	8	64		
WEIGHT:	8	5	40	8	64		
POWER:	8	5	40	8	64		
GROWTH ACCOM.							
EXTENDABILITY	7	4	28	9	63		
INSERTABILITY	8	7	56	9	72		
TOTALS:	100		643		734		0

C-2

3.5.2 Discussion

A stand-alone SDP represents a single box, fully tested by the vendor and containing the standard complement of memory and I/O capability. It represents, in fact, a common element of the commonality concept. It is also a fixed configuration, pre-defined to envelope the requirements of all assigned applications, and is, therefore, less than efficient in terms of technical utilization. It provides an adequate solution for the application requirements but may be deficient for some growth concepts. Extendability, for example, would be limited by the relatively few spare module positions generally available within the unit, and when modules are added, they must be added for all applications regardless of need in order to perpetuate commonality. Technology insertion may also be difficult to implement depending on the design and form of the internal modules; total SDP replacement may be required.

The missing attribute of this apprach is a flexibility that could be provided by applying the commonality control at a lower level. The intense competition between commercial back-plane vendors will generate superior products and provide at least a de-facto, if not an institutional, (i.e. IEEE) standard. The growing OEM and after market support for these back planes is producing a broad variety of processor in both general and special purpose architectures, along with memory and I/O products sufficient to satisfy demanding system requirements. 'Standardization' of a specific back plane and card format for the Space Station Program applications will allow assigned or dedicated processing nodes to be established that can be tailored as desired.
This approach facilitates:

- extendability
- technology insertion
- maintenance and repair

- reconfiguration for added memory or I/O requirements

- re-architecture for the implementation of unique computer approaches.

The penalty for this flexibility are the added configuration management requirements to track the larger number of common elements, i.e. circuit cards, and the configurations of the processing nodes.

The pay-offs for this approach are:

- decreased operational costs primary due to reduced spares capitalization and reduced 'scrap' costs, and,

- flexible, efficient processing nodes that can be tailored to specific applications.

4.0 Conclusions/Open Issues

This study effort has identified the preferred options to a number of the significant issues concerning the space qualified data processing hardware. These results indicate that the SDP should be:

- a standard 1750A unit with an option for at least a common AI processor

- fully radiation qualified to the POP levels, and,

- designed without special reconfigurabilities for fault tolerance

The use of a 'standard' back-plane and circuit card format should be considered to implement a lower level of commonality.

XII. DISTRIBUTED DATA BASE MANAGEMENT SYSTEM

DISTRIBUTED DATA BASE MANAGEMENT
TRADE STUDY REPORT

1.0 INTRODUCTION

1.1 BACKGROUND

A basic assumption made in this trade study has been that the Data Base Management Systems (DBMS's) that will be used in the Space Station Program (SSP) will not be designed from basic data base principles but rather will be vendor products (possibly modified for a specific application). This is necessary to realize cost effectiveness which is a generic trade criteria. The organization of data structures within the DBMS, sizing of storage and data processing are design decisions made after selecting a DBMS. All commercial products are targeted to a host environment consisting of a machine and associated mass storage devices running under some operating system. The distributed data base system has other elements as depicted in Figure 1.1.1. The host environment also contains the user interface and network interface running under a communication software package. The selection of a DBMS is coupled with the selection of all these host environment support elements. Although it is assumed that the DBMS trade is a commercial product selection process it is still necessary to understand the characteristics of DBMS's so weighted trade criteria can be established on the basis of data manipulation requirements. The data manipulation requirements are user driven. The characterization of user data manipulation requirements and the characterization of the data collection method and location(s) are the primary drivers in determining the desired DBMS characteristics such as:

data structure
distribution/partitioning
replication/recovery
interface
presentations and reports

The details of various vendor options can be traded to establish the best match to the requirements. The problem boils down to understanding the features of various vendor options and understanding the diverse requirements of various SSP SSIS data handling entities. These SSIS entities are distinquishable because of unique data views and locations. Some segment(s) of the SSP DB exist(s) at each SSIS entity. At each of these entities there will

PRECEDING PAGE BLANK NOT FILMED

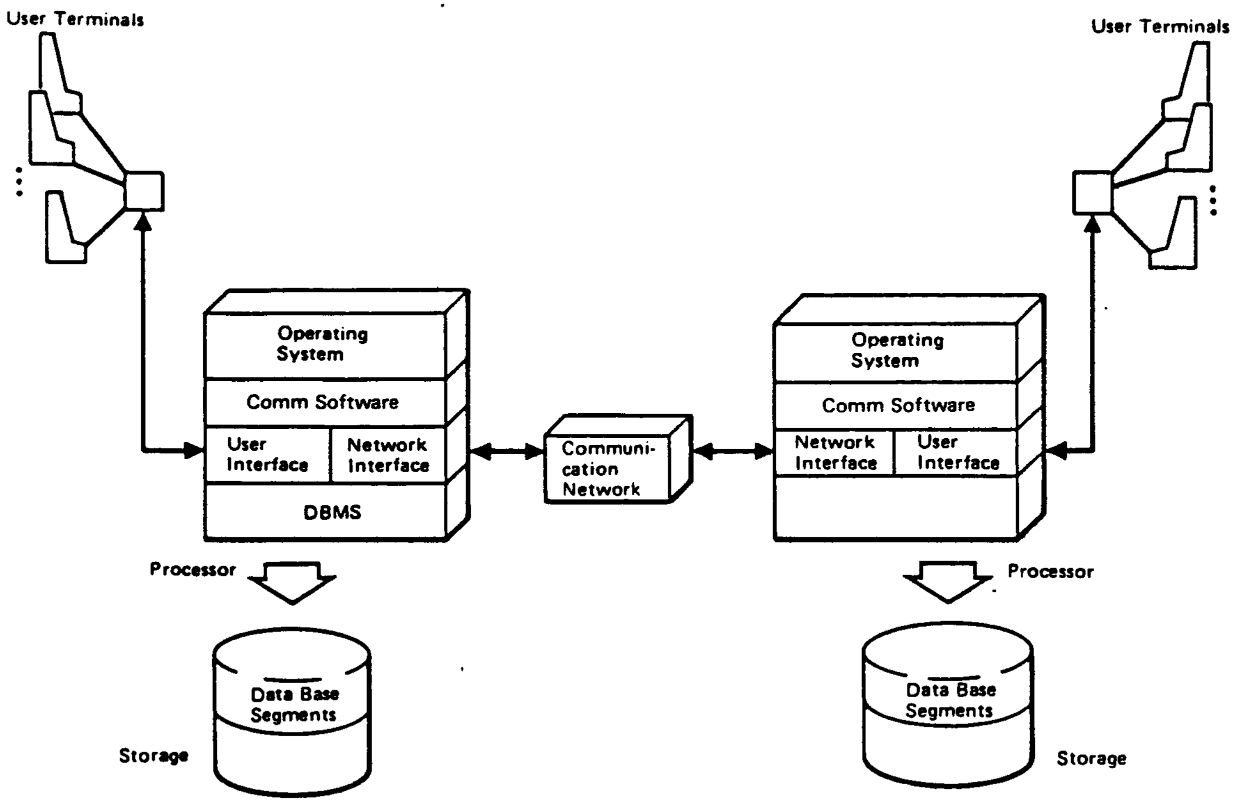


Figure 1.1.1. Distributed Data Base Management Systems

be individuals (or teams of individuals) called data base administrators (DBA's) with the responsibility to make the data base design decisions. These DBA's will have to understand the requirements of DB users and available vendor options to make decisions. This trade study will support the DBA's in these decisions.

1.2 ISSUES

1.2.1 DISTRIBUTION/CONNECTIVITY

One major decision will be to define to what extent each data base is reachable from various geographic and space locations. This aspect of data sharing will drive network design and universal naming conventions for the data structures (data sets or relations). The complexity of DB interfaces will also be driven by whether we have homogeneous DB's or heterogeneous DB's.

1.2.2 ADMINISTRATION

The issue here is to insure that the authority for data base management is established early in the program and this authority is not distributed so widely that DB state becomes difficult to control. The assignment of administrators needs to be done as DB entities are defined and clear partitions are established.

There is a continuum of options here ranging over the spectrum of possible granularities given to the DB segments. Some common sense must be applied to assigning administrative authority over DB segments.

1.2.3 REPLICATION/RECOVERY

There is a possibility to implement a recovery scheme by augmenting a commercial product. This option can be considered if the survey of products establishes that adequate recovery is not provided or if a vendor option is selected because of superior capabilities other than recovery and augmentation is appropriate. Additional back-up by replication of the DB is an option. This may be accomplished by replication in the archive.

1.2.4 PARTITIONING

1.2.4.1 SPACE/GROUND

Partitioning of data between space and ground is a major design decision. Data storage and large DBMS software packages in space could present a higher cost for computational and storage devices because they must be space qualified.This must be traded against the bandwidth needed for space to ground transfers and queries. The response time for space queries will have to be analyzed to determine if acceptable times are realizable. For the most part this seems possible since the majority of data exchange will be non-interactive (i.e., mainly large text block transfers).

1.2.5 ANCILLARY DATA GROUPING

The performance of an O/B system which allows users an option to acquire ancillary data and append that data to experiment data will be highly dependent on the nature of the ancillary data blocks. This presents the O/B DB designer with decisions concerning ancillary file structures and granularity of ancillary data access.

A common block required by most users is the vehicle state (attitude, position vector,time). Other groupings need to be established after user requirements are understood. These groupings should be such that the O/B data network is not loaded down with data transfers containing a majority of data that will be discarded.

1.2.6 ARCHIVE RESPONSIBILITY

A major DB design decision that has impact at the program level is to determine where the functional responsibility for archiving data resides. The options are some reasonable assignment of the following data groups to the major data handling centers.

DATA	CENTERS
Engineering	Data Handling
Ancillary	Space Station Control
Customer	PL Control
	Regional/Discipline

1.2.7 RECORDER MANAGEMENT

The option to provide bulk recording in the space segments of the DB to aid in managing the telemetry link is an area for consideration and couples tightly with the O/B DB design. The management of these recorders is another area needing consideration (DMS or C&T).

1.2.8 O/B DB OF SUBSYSTEM HISTORY DATA

Another decision facing the O/B DB design is to establish how much and what subsystem history data will be held O/B for O/B status support. This design decision couples with the need for O/B autonomy and the communication system capability to support interactive communication with the ground segments of the DB.

1.2.9 COMPATIBILITY OF DB's

The use of heterogeneous institutional facilities is a major decision. Existing data base management systems are to be provided to the Space Station Program by the Level C centers. This means dealing with heterogeneous DBMS's and the operating systems that they run under.

1.2.10 STRUCTURE

The selection of a DB structure for each of the SSP DB's will be an important decision and require a complete understanding of the data characteristics and user intentions for data manipulation. Any data structure selected can be abused and result in poor performance if other factors are not considered. The organization of data within the constraints of the DBMS features can be called the DB architecture. It may turn out that this architecture is more important to performance than the DBMS data structure. The big decision that will be encountered designing the various DB's for the

SSP (besides the selection of a DBMS) will be the characterization and desired organization (i.e.architecture) of the data within each DB segment. Data can be broadly categorized into three groups:

a) Sampled data(sequential numerical; sensor data)
b) Text (alpha numeric; s/w prgms,presentations)
c) Associable (tables with correlatable data; mission data)

This characterization will aid in determining the DBMS functions needed to manipulate each category of data. For Category 1 a flat file server may be an adequate DB manager option. Category 2 requires more DB manager services, mainly related to word processing. Category 3 represents data which must be organized into records or tables so additional information can be extracted by queries which result in presentations(reports) to the user. For Category 3 we must decide on the data storage structure (i.e. relational, hierarchical or network). This decision and the organization of data within that structure (i.e., architecture of DB) will determine the DB performance (throughput and response).

1.2.11 O/B INTERACTIVE CAPABILITIES

This issue couples response requirements for onboard DB interaction with the requirement for onboard autonomy. At issue is what DB segments will be needed onboard because of autonomous operations and what segments will be needed onboard because interaction through communication links to the ground have unacceptable delays or the bandwidth is not available.

1.2.12 GROWTH ACCOMMODATION

Predicting growth in data storage is another design aspect which is critical. Large structures may become unmanageable requiring further partitioning and the data base managers must be flexible to absorb restructuring without impacting application software. Vertical growth (i.e. built-in margin) is an option and horizontal growth (i.e. expansion by adding capacity without impact to existing structures) is another option. The DB designer should factor growth into design decisions.

1.2.13 ARCHIVE STANDARD FORMAT DATA UNITS (SFDU's)

The SFDU recommendations made by the CCSDS may be built into the DB archive capability. This is especially pertinent to the archiving of ancillary and scientific data. It is not clear at this time if the SFDU "labels" are related to catalogue names used by the DBMS to retrieve data blocks. Further study and decisions are required to integrate the standard formats into the DB management.

1.3 TRADE STUDY CRITERIA

1.3.1 GENERIC

The generic study criteria are listed below:

- Cost
- Risk
- Performance
- Standardization/Commonality
- Growth/Technology Insertion

The specific performance criteria considered for the DB trade study are:

- Availability
- Ease of use (change, query)
- Response time (query, update)

1.3.2 TRADE STUDY UNIQUE

Trade criteria unique to the DB trade are:

- User interface
- Growth Management
- Security

1.4 APPLICABLE OPTIONS

Data Base Management (2.1.1)

1.5 ALTERNATIVES

1.5.1 LARGE RELATIONAL DATA BASE PRODUCTS

For many of the SSP DB segments a large relational DB product will be the answer. The alternatives for relational DB's and associated host environments are listed below. Each commercial product has unique characteristics which can be used to evaluate applicability to the various data base segments. The complete set of characteristics is not included for all products because of the volume of material but is included in the referenced option report.

TABLE 1.5.1 LARGE RELATIONAL DATA BASES

SYSTEM	VENDOR	CPU/OS's	COST	DEV HISTORY
SQL/DS	IBM CORP	* 370/DOS/VSE with CICS * VM/CMS		Commercial version of SYSTEM R
ORACLE	ORACLE CORP	DG/Eclipse VAX/VMS,UNIX 370-compatable /VM-CMS M68000/UNIX DEC PDP/RSTS, UNIX others		Developed as a DB manager for SEQUEL (now SQL)
INGRES	RELATIONAL TECHNOLOGY INC	VAX/VMS,UNIX M68000/UNIX others		Based on the system developed at the Univ. Calif/ Berkeley
	BRITTON-LEE INC	VAX/VMS Z80/CPM Univac 1100 Datapoint 100 DG Eclipse PDP 11/UNIX		Developed as a back-end database processor using a QUEL interface
iDBP	INTEL CORP	None announced		Developed for micro and office automation appl.
RAPPORT	LOGICA LIMITED	25 mini's and mainframes		
NOMAD	D&B COMPUTERS INC	370-compatable/ VM/CMS NONSTOP II		Originally a reporting system action processing system
SMARTSTAR	SIGNAL TECHNOLOGY INC.	VAX		

1.5.2 ONBOARD OPERATIONAL DATA BASE MANAGEMENT SYSTEM (ODBMS)

An alternative that must be considered for the onboard operational DB segment is to use a commercial product. Some modification may be required if the product is not available for the processor being considered as the interface to the onboard mass storage. Some form of a UNIX based file service may be adequate for onboard storage of software programs and text files. The LOCUS system is a possibility and references are provided in the DBMS option report. Another distributed system to consider is the DOMAIN system described in reference 29 of the report. The assessment of options for the onboard DB must consider many factors:

- o communication with the ground DBMS (homogeneous/heterogeneous?)
- o performance (response,...)
- o the inherent program requirement to minimize costly onboard storage
- o technical issues related to autonomy and automation such as: onboard diagnostics, training, operations manuals, ...

The content of the onboard DB will be a prime driver in selecting an appropriate onboard DBMS. The Task 1 function list suggests that the following are potential segments for residence onboard:

<u>ONBOARD DATA BASE CONTENT</u>

DOCUMENT MANAGEMENT
- MANUALS(PROCEDURES)
- DAILY SCHEDULES
- DIAGNOSTIC SUPPORT(SCHEMATICS)

SOFTWARE

CHECKPOINTS

SUBSYSTEM TREND DATA

REAL-TIME DATA

BUFFERED DATA(RECORDERS)

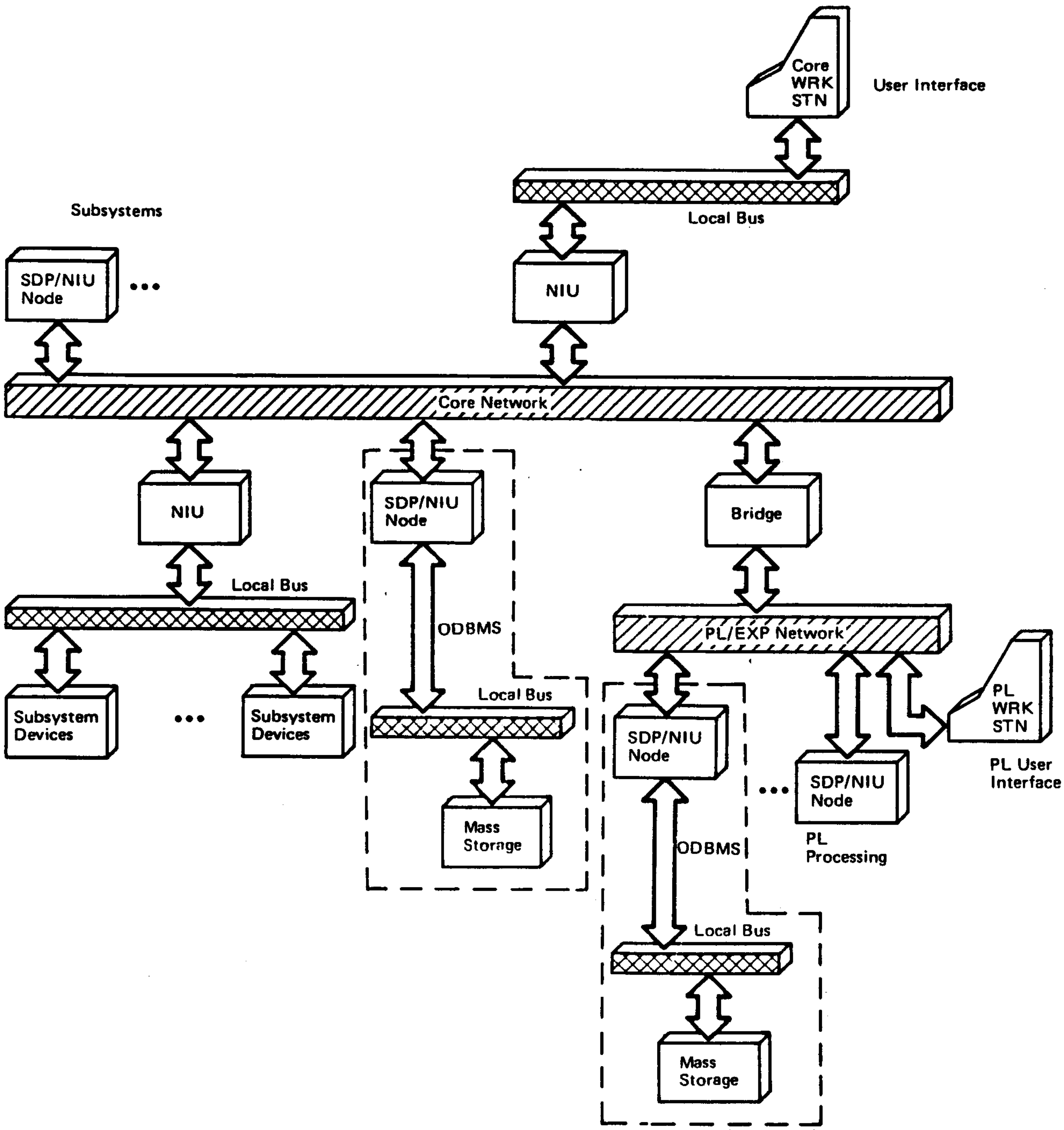


Figure 1.5.2.1. Onboard Data Base Management System Interfaces

The ODBMS manages this data in support of the subsystems, PL's, experiments and customers as depicted in Figure 1.5.2.1.

Each subsystem has within its own memory space data that consists of:

a) Sampled data (raw input data from sensors)

b) Derived data (computed on basis of stored algorithms)

c) Static data (algorithm constants that may change only for reconfigurations or mode changes)

The first two categories correspond to subsystem trend data and real-time data.

If all the subsystems were totally autonomous there would be no need to share this data. The subsystems are not totally autonomous but rather interact with onboard crew members and ground support to varying degrees. Subsystems also interchange data. Interchange of data between subsystems can be through predefined messages or through a data base. Predefined messages are much faster (without data base intervening) and are the preferred alternative for all subsystem exchanges. There are some exceptions. Flexibility is needed in defining telemetry and user interface data retrieval. If a data base is used for interchange, then some form of "data acquisition" must be supported to place the data in the data base. This is especially true in a distributed system where the subsystem data is distributed among many processors. The data acquisition function moves data segments into one data processor and manages that data.

1.5.2.1 DATA ACQUISITION

One alternative is to have the Onboard Data Base Management System (ODBMS) control the storage and retrieval of all data generated by subsystems and intended to be used by user interface and telemetry. (Note: in the following discussion subsystem is interchangeable with PL/EXP) The control of this storage could be initiated by the subsystems. This is depicted in Figure 1.5.2.1.1. Subsystems could initiate the storage of current and historical data at the time of initialization (or later as a result of a software reconfiguration) by sending a request for service to the ODBMS. The details of this service are explained in Appendix A.

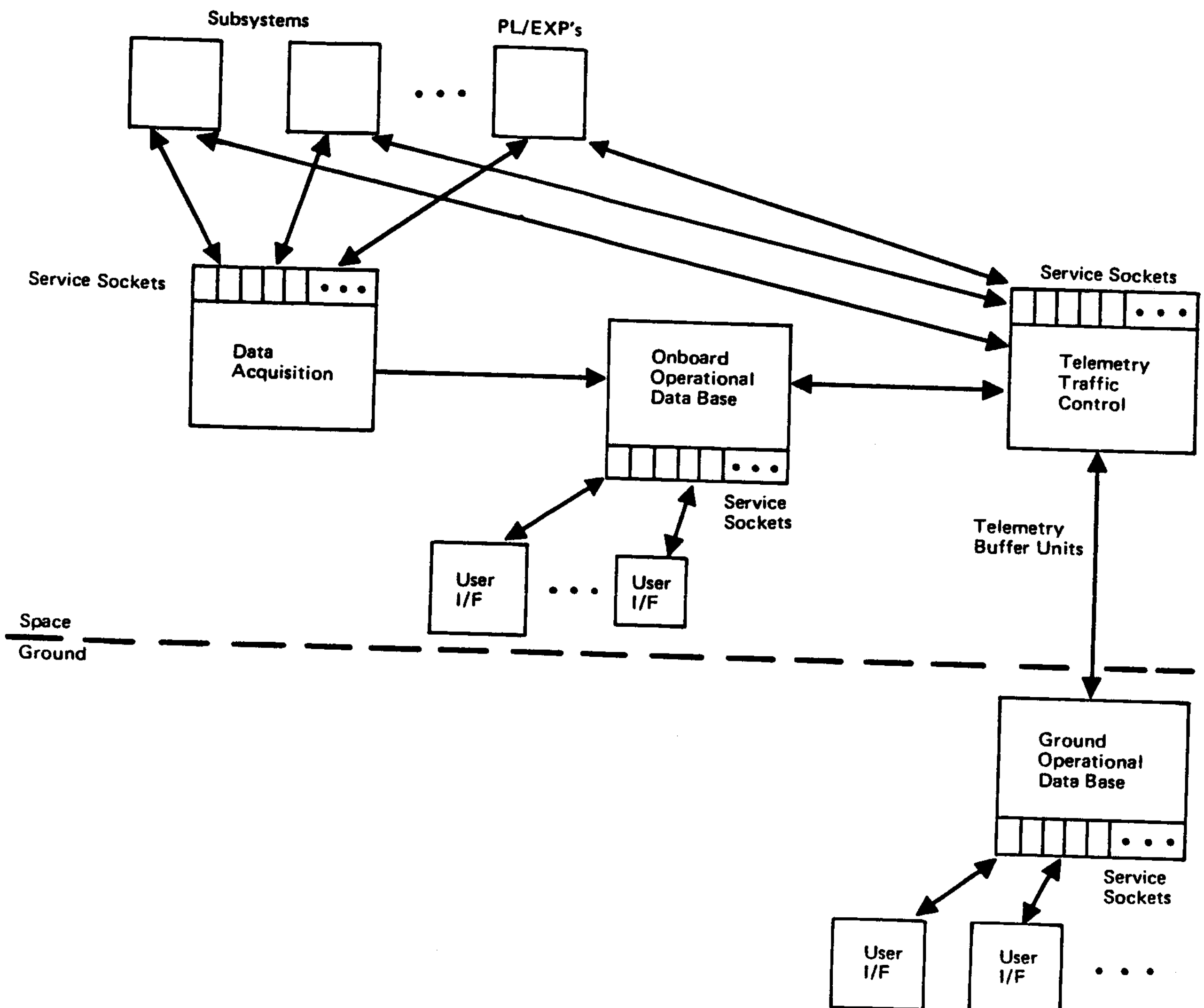


Figure 1.5.2.1.1. ODBMS/User Interface/Telemetry Functional Interface

Another alternative is for each of the subsystems to maintain a separate data base of parameters and accept requests for data from the user interface (just as the ODBMS would have done) and build the telemetry buffers directly. This would place more responsibility on the telemetry subsystem to do the data merging from multiple subsystem inputs (see Section 1.5.2.3 for the ODBMS interface to the telemetry buffer unit building service). Also, the workstation programs would not have a central directory to interrogate to see if a parameter was available (unless the directory was kept by ODBMS with a mapping to the subsystem owner) and therefore would have to communicate with all the subsystem data bases until the parameter was located. In addition, the service to deliver historical data or current data to the user interface would have to be carried in all subsystem processors along with the software to collect data into a data base. In effect, we would have duplicated the entire ODBMS in each subsystem computer and still a user would have to communicate with all subsystem ODBMS's to find the data. This is a relatively unattractive alternative.

In the alternative where the central ODBMS keeps the directory of all parameters to be shared but the subsystems own the data, requests for data would come to the central ODBMS and the central ODBMS could go get the data or alternatively direct the requestor to the data. This would be an alternative for user interface data where a "one-time" data exchange might occur. The direction to the data in subsystem memory space would be on a parameter by parameter basis and could consist of a message returned to the requestor with a subsystem ODBMS mailbox address where data can be requested. The user must then go get the data. The potential delays in this approach appears to make it unattractive. If the central ODBMS gets the data, the potential delays are still present because the central ODBMS must go and collect data on a parameter by parameter basis by communicating with subsystem ODBMS's.

1.5.2.2 USER INTERFACE

The ODBMS could support user interface programs which are loaded into the workstations. These programs could support graphics presentation and tabular formats defined by the user. The workstation could operate in any of three modes.

One mode would be called the query mode since the data base is queried and data is retrieved and presented to satisfy the query. The other two modes would be menu and command. The menu mode supports the user by help panels which define all the configurations allowed at the workstation. The command mode presents panels which allow command and control of subsystems. These panels would be restricted by authorization access codes. The command panels could be predefined and only allow selection of predetermined configurations or modes and entry of parameters within predefined limits.

The query mode interfaces to the ODBMS for delivery of data which is then formatted by workstation programs. The format (plots, tables, etc.) could be selectable by the user.

1.5.2.3 COMMUNICATION SUBSYSTEM INTERFACE

Telemetry buffer units (TBU's) could be built and their content identified by a function called Telemetry Traffic Control (TTC). The TTC function delivers TBU's to the communication system buffer space for modulation and transmission through the communication link. TBU's contain subsystem data, telecommands, and telecommand acknowledgements. The process of building a TBU utilizes priority assignments and telemetry packet segmentation. The TBU may contain multiple telemetry packets (as defined by CCSDS) or a telemetry packet fragment. The TBU size will be limited to the communication subsystem toggle buffer size. Sending TBU's close to the buffer size would be essential to avoid bandwidth loss when a toggle buffer is still being filled and transmission of the other is complete.

The TTC interface to the ODBMS has several alternatives. The simpliest alternative would be to assume that the subsystem records collected into the ODB by data acquisition function are identical (rates and content) with the telemetry requirements to the ground data base. This alternative is depicted in Figure 1.5.2.3.2 where the ODB supports TTC. In this case the grouping of data into a TBU would be by rate group and priority. A rate monotonic priority scheme could be assumed. (i.e., the higher the rate, the higher the priority).

The identification of the contents of periodic TBU's could be constructed by TTC using the UNIQUE-OBJECT-NAMES (UON's) defined by the subsystems and maintained by the ODBMS directory. After deciding what the contents of each periodic TBU will be (possibly multiple periodic subsystem records), the TTC would construct a message containing the UON's that would be in the periodic TBU's and attach a unique TBU name (UTBUN) and transmit to the ground data base. The ground DB would have a similar server to the ODBMS, accepting messages to define periodic TBU's.

The layout of this message to the ground data base would have the following format.

Figure 1.5.2.3.1
UNIQUE TELEMETRY BUFFER UNIT IDENTIFICATION MESSAGE TO GROUND DB

	UTBUN	
	RATE – GROUP	
.	UON 1	FIELD 1
.	UON 2	FIELD 2
"N"	.	.
.	.	.
.	.	.
	32 bytes	1 byte

The TTC would then maintain a schedule of TBU's that must be built periodically and perform this function. Each time the UTBUN would be attached as a header before transmission of a UTBU to the ground DB. The ground data base would maintain a directory of UON's available for ground user interface.

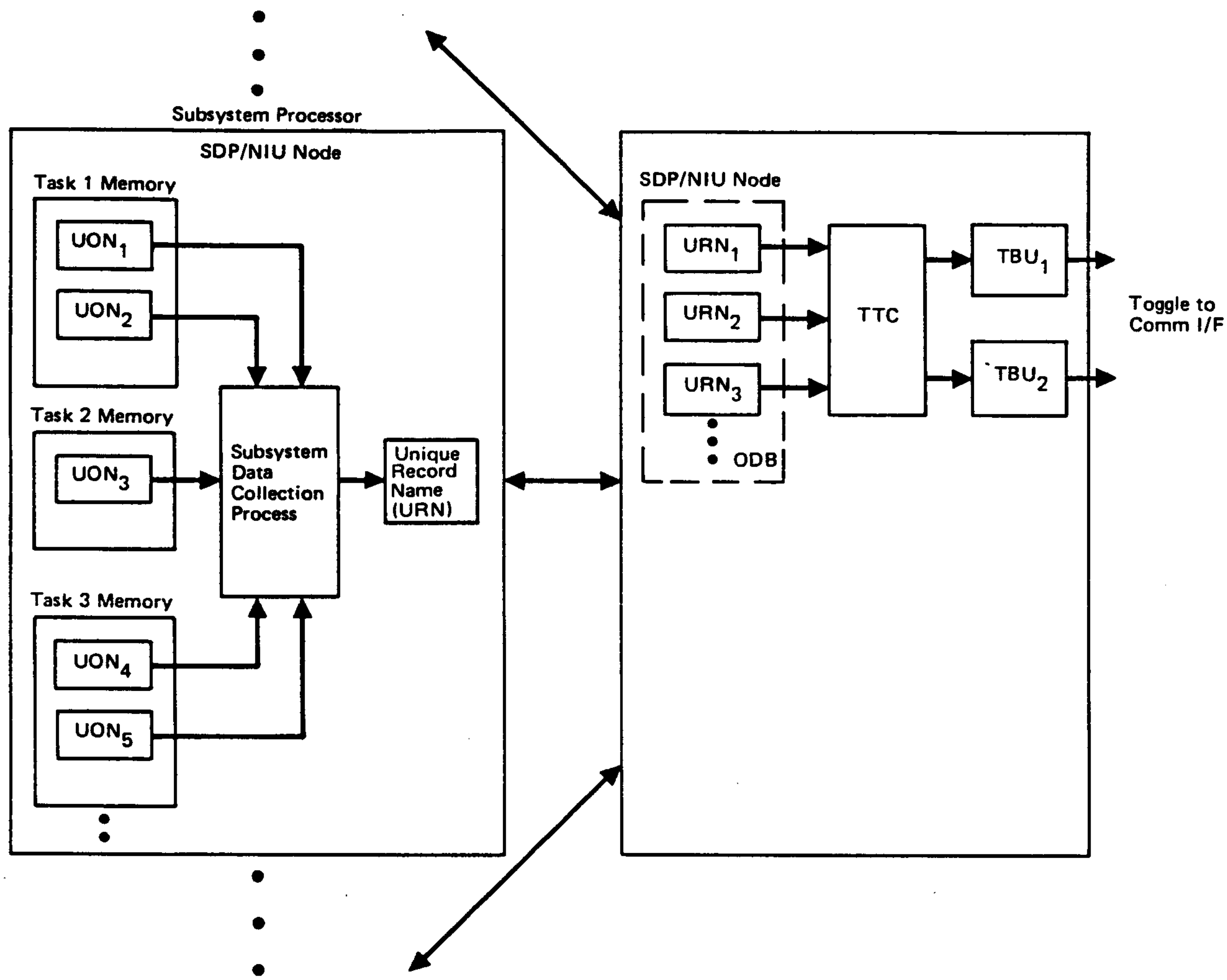


Figure 1.5.2.3.2. TTC Interface (Alternative 1)

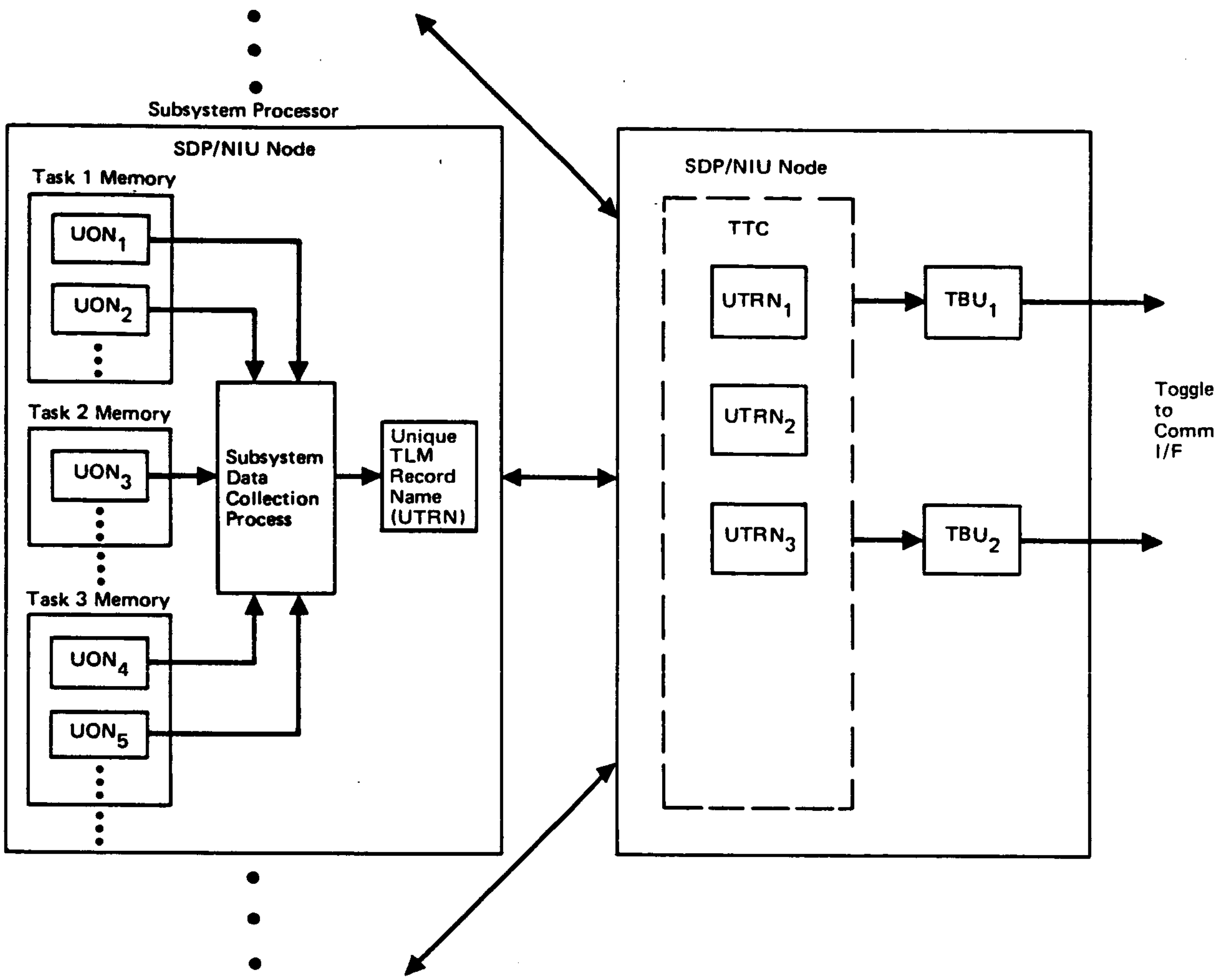


Figure 1.5.2.3.3. TTC Interface (Alternative 2)

The other alternative is to allow the telemetry parameters to be defined independent of the ODBMS subsystem record definitions. Within this alternative are several sub-alternatives. The subsystems could establish an interface to the TTC (much like the one between the ODBMS and subsystems) and communicate telemetry records directly. This would take the ODBMS out of the loop completely. This alternative is depicted in Figure 1.5.2.3.3. Alternately, a list of parameters (UON's) and rates could be sent to TTC which in turn would gather the data from the ODB and build rate grouped TBU's. The overhead associated with this sub-alternative makes it unattractive.

Some TBU's will contain aperiodic data. Data for these TBU's could be communicated directly to TTC and bypass the ODBMS. These TBU's will not be able to use the unique content identification approach (UTBU can only be used for periodic data defined with UON's). These TBU's will have to carry content identification as part of the TBU. The content identification could consist of a variable length leader defining the number of segments in the TBU and their locations within the TBU. [The final destination is a part of the TLM packet format (CCSDS)]. TLM packet fragments delivered in TBU's will have to be reconstructed in the ground data base before the entire TLM packet is forwarded to the final destination.

1.5.2.4 MASS MEMORY CONFIGURATION

There are several issues associated with the configuration of mass memory onboard the space station; distribution, flight build-up, redundancy and integration with the other DMS elements (SDP's and NIU's).

The distribution issue addresses the physical distribution within the space station structure and also distribution on the PL and core networks. Figure 1.5.2.4.1 shows two alternatives for distribution on the PL and core networks. The first alternative has all the mass memory attached to a SDP/NIU node on the core network. This alternative would mean that PL/EXP interfaces with ODBMS would be through the network bridge. This could present a bottleneck. The ancillary data service would be across this interface in either alternative since ancillary data originates within the core network.

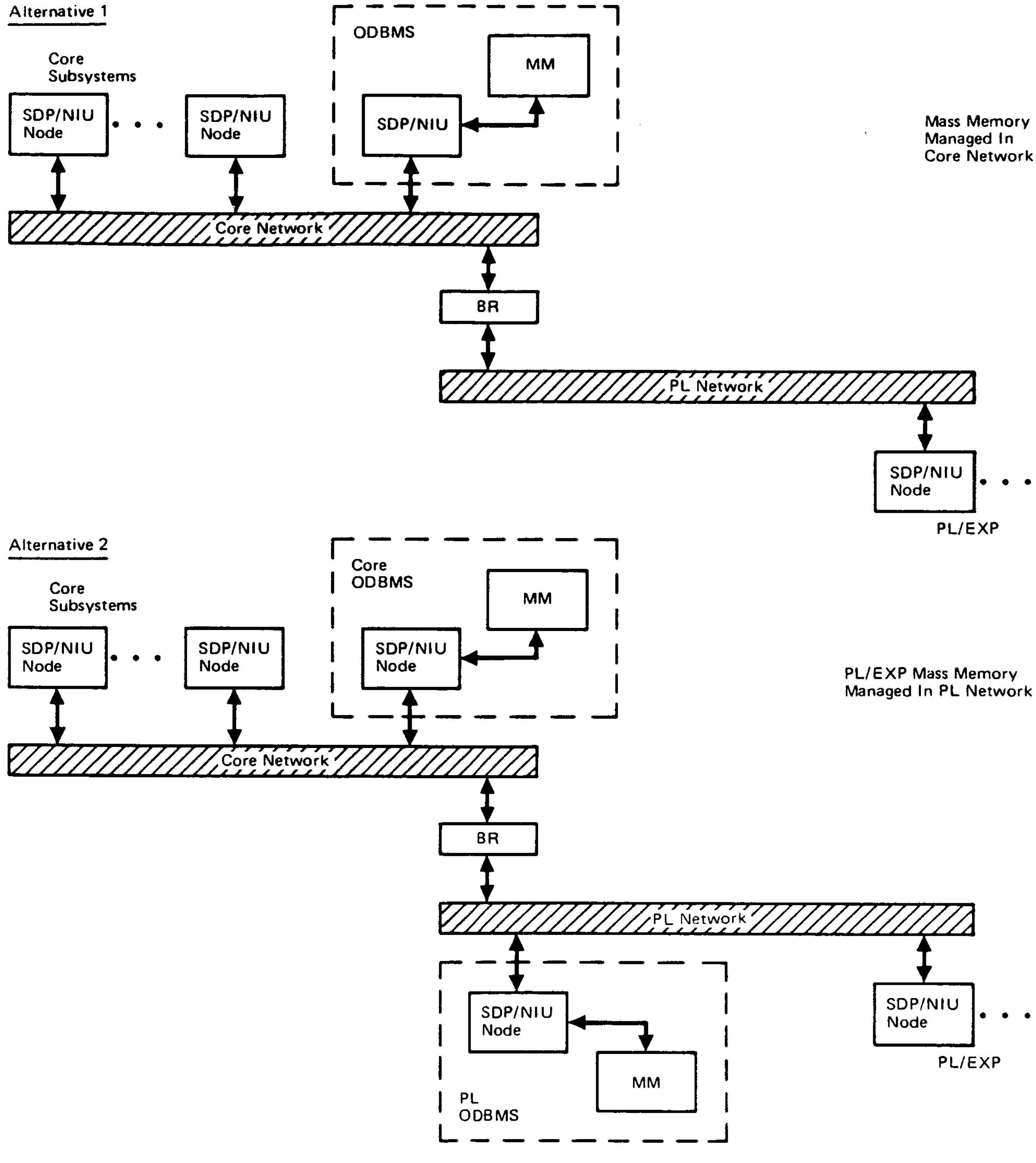


Figure 1.5.2.4.1. ODBMS Alternatives (PL/Core Distribution)

The first alternative has the advantage of having only one ODBMS resident in the SDP/NIU nodes. The second alternative has separate mass memory elements attached to a PL network SDP/NIU node. The ODBMS resident in this node would service PL/EXP users. This eliminates some of the bridge traffic but potentially introduces the complexity of communication between two ODBMS's. In addition, onboard complication would be introduced if these two ODBMS's were not homogeneous (which would be an alternative).

Another issue is the flight build-up of mass memory. The first flight delivers the transverse boom structure. It appears to be advisable to minimize the mass memory on the truss because of difficulty in maintenance and to minimize the volume of DMS on the first flight. On the other hand the ODBMS will have functions required from the first flight that need mass memory elements. These functions are: SDP and NIU program loads, telemetry interface buffering for TDRSS loss and checkpoints for restart. The first alternative depicted in Figure 1.5.2.4.2 is to have the SDP/NIU nodes contain a nonvolatile memory (as well as working memory) where programs could be loaded and used at start-up. This non-volatile memory would also have to be used by ODBMS for the other functions (checkpoints and telemetry buffering) or else these functions would not be supported. There is an alternative to just support checkpoints using the SDP non-volatile memory for the first and second flight. The mass memory units would be added later on a flight with a pressurized module. One disadvantage of this alternative is that the ODBMS interface to memory is changed when the external mass memory becomes available. Also the ODBMS needs to run redundantly otherwise loss of an SDP would mean loss of the ODB. Communication between ODBMS's in SDP's would be needed to maintain multiple copies of the ODB.

The second alternative is to have mass memory units delivered on the first flight. If these are highly reliable units, this is also a viable alternative. The possibility of adding redundancy at a later flight is another alternative. A ground uplink to the SDP/NIU nodes can be used to augment the reduced onboard redundancy.

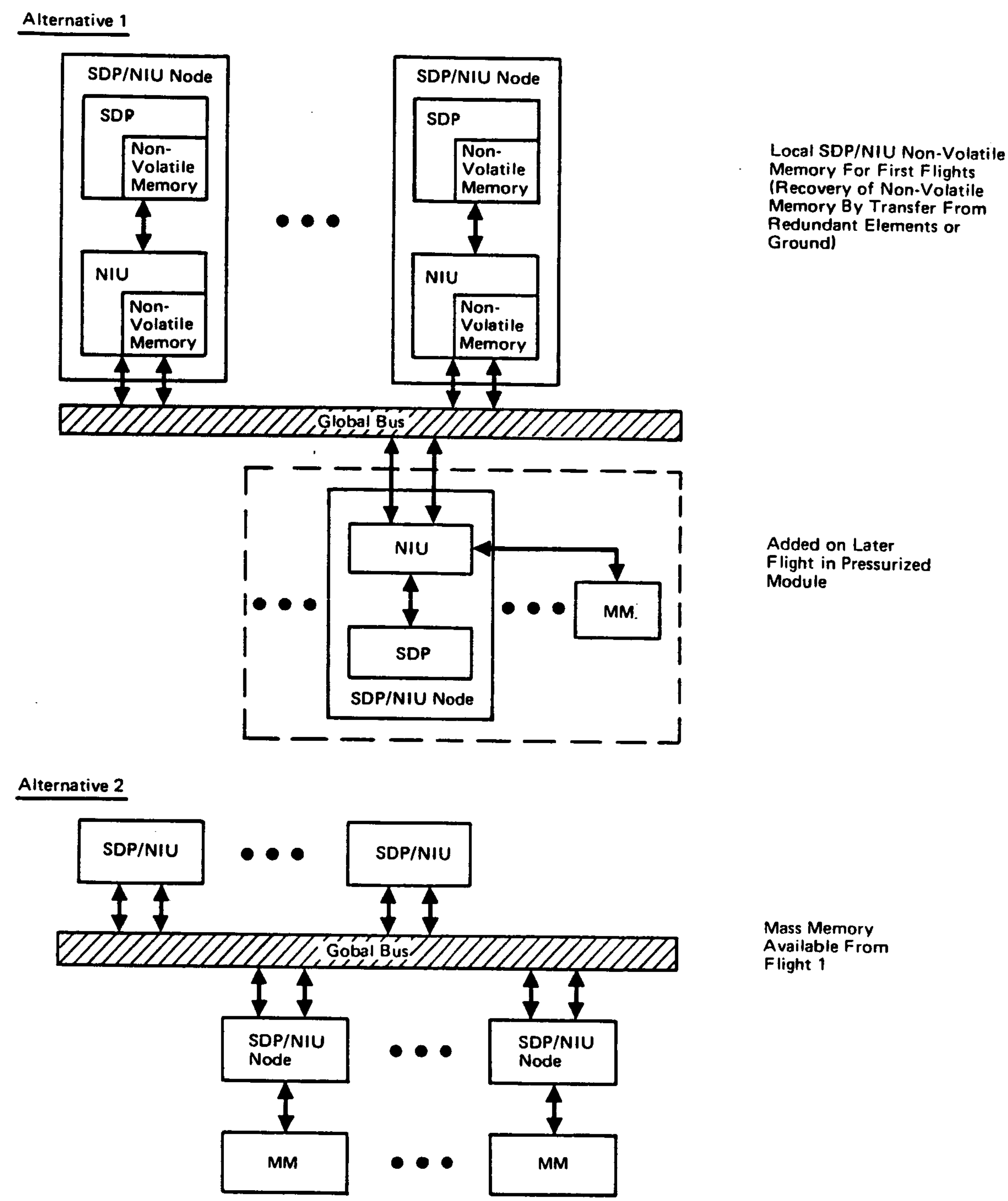
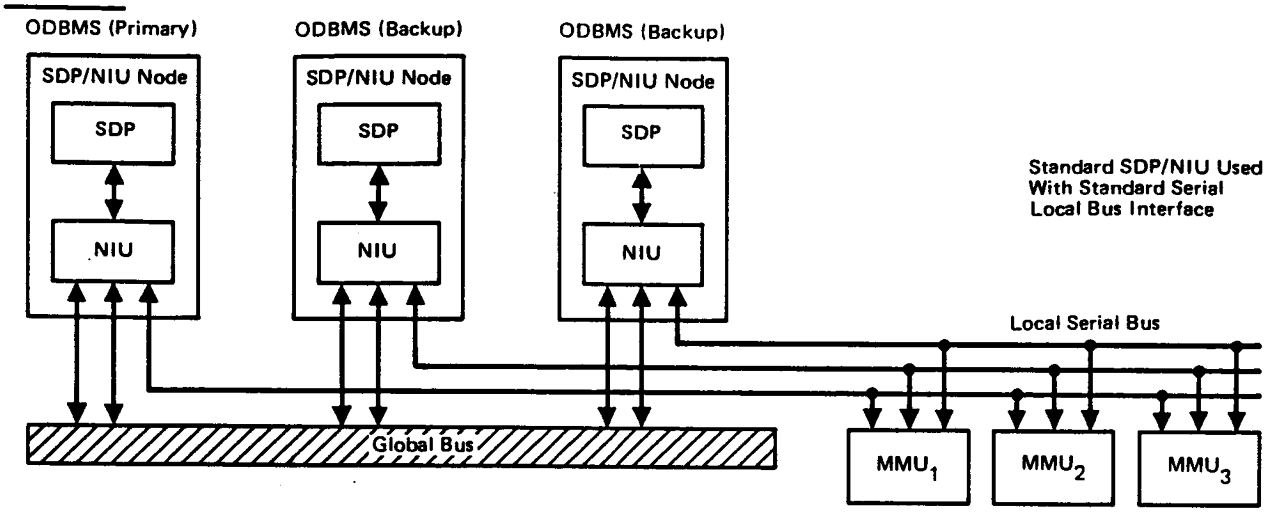


Figure 1.5.2.4.2. ODBMS Alternatives (Flight Build-Up)

The redundancy and integration of mass memory with the other DMS elements couples tightly with the flight build-up issue. The first alternative depicted in Figure 1.5.2.4.3 is to have the mass memory units separate from the SDP/NIU nodes and have communication to the MMU's on a Standard Serial local bus (the same bus used for subsystem sensors and effector communication). The ODBMS would be resident in the local SDP/NIU node controlling the MMU's. The redundancy in this alternative would be three MMU's attached to a SDP/NIU triad. Any of the SDP/NIU's in the triad could be in communication with any of the MMU's (i.e., multiple ports to MMU's). Since local buses are used to communicate to the MMU's, the SDP/NIU's and MMU's will have to be co-located. This would mean that this alternative is coupled with delivering all the MMU's on the first flight (transverse boom) or on flight 3 (habitat module). A build-up in redundancy would not be possible without running local buses from the truss to a pressurized module (which is undesireable). Alternative two is the same as alternative one except a parallel bus is used for NIU to MMU interface. This addes a special port to the backend of the NIU. This alternative would be a fall back for alternative one if the data rates on a serial bus were determined to be inadequate. The disadvantage is the addition of a third port to the NIU backend. The NIU backend already must support serial local buses and the SDP interface.

The third alternative is to have an integrated SDP/NIU/MM node. (See Figure 1.5.2.4.3) In this alternative the communication between mass memory and the computing elements is on an internal bus. The disadvantage of this alternative is the creation of a non-standard node. The advantage is the potential for a more manageable and higher rate communication to the mass memory. Another advantage would be the flexibility for redundancy build-up. One of these special SDP/NIU/MM nodes could be delivered on the first flight and uplink used as a fall back. The redundancy could be upgraded by delivering two additional nodes in habitat module one.

Alternative 1



Alternative 2

Same as Alternative 1 But With Parallel Interface Between NIU and MMU.

Alternative 3

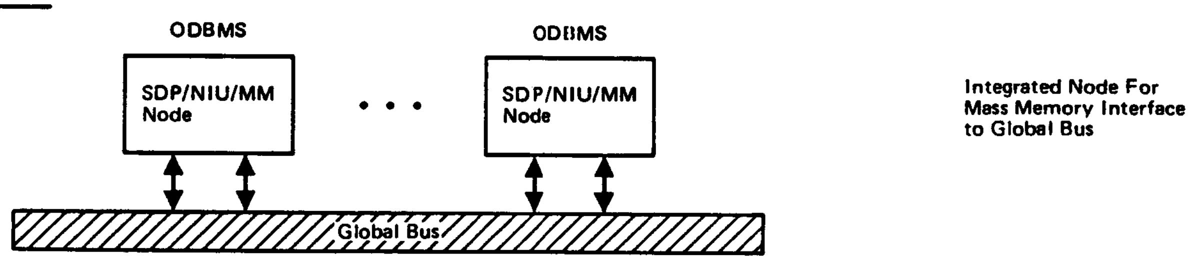


Figure 1.5.2.4.3. ODBMS Alternatives (Mass Memory Integration)

1.5.3 SPACE/GROUND PARTITIONING

The alternatives for each DB entity is to have the DB fully partitioned (that is each of the DB segments resides at exactly one location) or fully replicated (that is each segment of the DB resides at all locations) or something in between. The problem with full replication is that updates must be exchanged to keep the copies consistent. Also, network delays can mean slow response. Partitioning the DB can result in improved performance by allowing a local computer to just handle local transactions (if the queries concern the local partition, otherwise, the other partitions must be acquired from the owner).

The alternatives that must be considered for space/ground partitioning is to replicate partitions of the data base in space when queries in that partition occur or have the queries relayed to the ground DB and responses returned to space. The same alternatives exist for ground query of space partitions. Partitions of the DB originating and being updated on a periodic basis could be kept in space and relayed to the ground for queries.

2.0 METHODOLOGY

The approach taken in this trade study is to consider all SSIS DB entities and then to concentrate on the characteristics of the SSDS DB embedded within the SSIS, in particular the Space Station Operational Data Base (ODB) and the interface to the ground data base. For the entire data base problem this approach translates into the following stages:

1. Define all the SSIS DB entities using the TASK 1 functions list and the basic premise that partitioning will be along established NASA institutional boundaries.

2. Determine which of these DB's are within the SSDS (exclude TMIS segments) while still considering required connectivity and interfaces of all segments.

3. Characterize the SSDS DB entities by:
   a) data content(type and source)
   b) functional manipulation requirements
   c) connectivity required

4. Define alternatives for commercial products applicable to the ground segments.

5. Define alternatives (commercial, modified commercial or "roll your own") for space segments.

6. Partition the SSDS DB's by space/ground segments

7. Partition the SSDS DB ground segments to as low a level as required to seperate by utilization (development,operational, scientific/PL) and also by interest domains, data types and DBMS functional requirements.

8. Trade alternatives and define recommended SSDS DB architecture including for each DB segment:

    data structure
    distribution/partitioning within segment
    replication/recovery
    interface
    presentations and reports

3.0 RESULTS

It is not the intention of this trade study to recommend a data base (i.e., a commercial product) for each of the ground segments but rather to suggest a reasonable segmentation of DB's and reasonable commercial architectures for each segment. The selection will be done by the data base administrators and management based on further evaluation of alternatives. It is the intent of the trade study to analyze alternatives for the onboard data segment and connection to the Space Station Control Center (SSCC) data bases and Payload Operations Control Centers (POCC).

3.1 DATA BASE SEGMENTATION

Within the SSP all data bases can be separated into TMIS DB's and other DB's. This separation allows the TMIS to be considered part of the SSIS but not the SSDS. This trade study is principally concerned with the SSDS DB's. The data base maintained by the TMIS corresponds to section 7.5 of the functions list, that is "Configuration Management". The TMIS is considered to contain the following data segments:

TABLE 3.1.1 TMIS DATA CONTENT

DATA BASE	DATA BASE CONTENT
LEVEL B SE&I MASTER DATA BASE (MDB)	- LEVEL A SPEC - SSIS CONFIG(CONNECTIVITY,ICD's) - REF CONFIG(DRAWINGS,TEXT) - WP ICD's
LEVEL B SE&I ENG MASTER SCH (EMS)	- SE&I SCHEDULES - S/W SCHEDULES - HARDWARE SCHEDULES
LEVEL C SE&I DB	- HARDWARE SPEC's - SUBSYSTEM ICD's - S/W REQUIREMENTS - SSE REQUIREMENTS

The need for data bases other than TMIS is clear from the Task 1 requirements in Appendix A of the DBMS options report. The segmentation of DB's other than TMIS is along established NASA institutional boundaries.

TABLE 3.1.2 DATA BASES OTHER THAN TMIS

DATA BASE	DATA BASE CONTENT
SSE DB	- SOFTWARE - MODELS - TEST SCRIPTS - RESOURCE SCHEDULING
TRAINING DB	- PROCEDURES - SCHEDULES
INTEGRATION SITE DB	- SOFTWARE - INTEGRATION SCHEDULES - PROCEDURES - TEST SCRIPTS
SSCC DB	- SPACE STATION STATUS - MISSION SEQUENCING - COMMAND PROCEDURES
POCC DB	- PLATFORM/PL ENGINEERING DATA - EXPERIMENT DATA
RDC/DDC DB	- SS ANCILLARY DATA ARCHIVE - PLAT ANCILLARY DATA ARCHIVE - FF ANCILLARY DATA ARCHIVE
SS OPERATIONAL DB	- MANUALS(PROCEDURES) - DAILY SCHEDULES - DIAGNOSTIC SUPPORT - SOFTWARE - CHECKPOINTS - SUBSYSTEM TREND DATA - REAL-TIME DATA - BUFFERED DATA (RECORDERS) -
COP/POP OPERATIONAL DB	- ENGINEERING DATA - SCIENTIFIC DATA
DHC DB	- LEVEL 0 DATA - SHORT TERM ARCHIVE - LONG TERM ARCHIVE

The entities identified and associated connectivity are listed in the following Table 3.1.3 and shown in Figure 3.1.1.

TABLE 3.1.3 : DATA BASE ENTITIES AND CONNECTIVITY

	HDQTRS	LVL B	LVL C				CONTRACTOR				SSE	SSCC	POCC	RDC	DDC	INTEG	TRNING	SS	COP	POP	DHC
			JSC	GSFC	MSFC	LEWI	1	2	3	4											
NASA HDQTRS		X																			
LEVEL B JSC	X		X	X	X	X															
LVL C JSC		X					X														
LVL C GSFC		X						X													
LVL C MSFC		X							X												
LVL C LEWIS		X								X											
CONTRACTOR 1			X								X										
CONTRACTOR 2				X							X										
CONTRACTOR 3					X						X										
CONTRACTOR 4						X					X										
SSE							X	X	X	X		X				X	X				
SSCC											X		X					X			X
POCC												X		X	X			X		X	X
RDC													X								X
DDC													X								X
INTEG SITE											X										X
TRAINING											X										X
SPACE STN												X	X						X		X
COP																		X			X
POP													X								X
DHC												X	X	X	X			X	X	X	

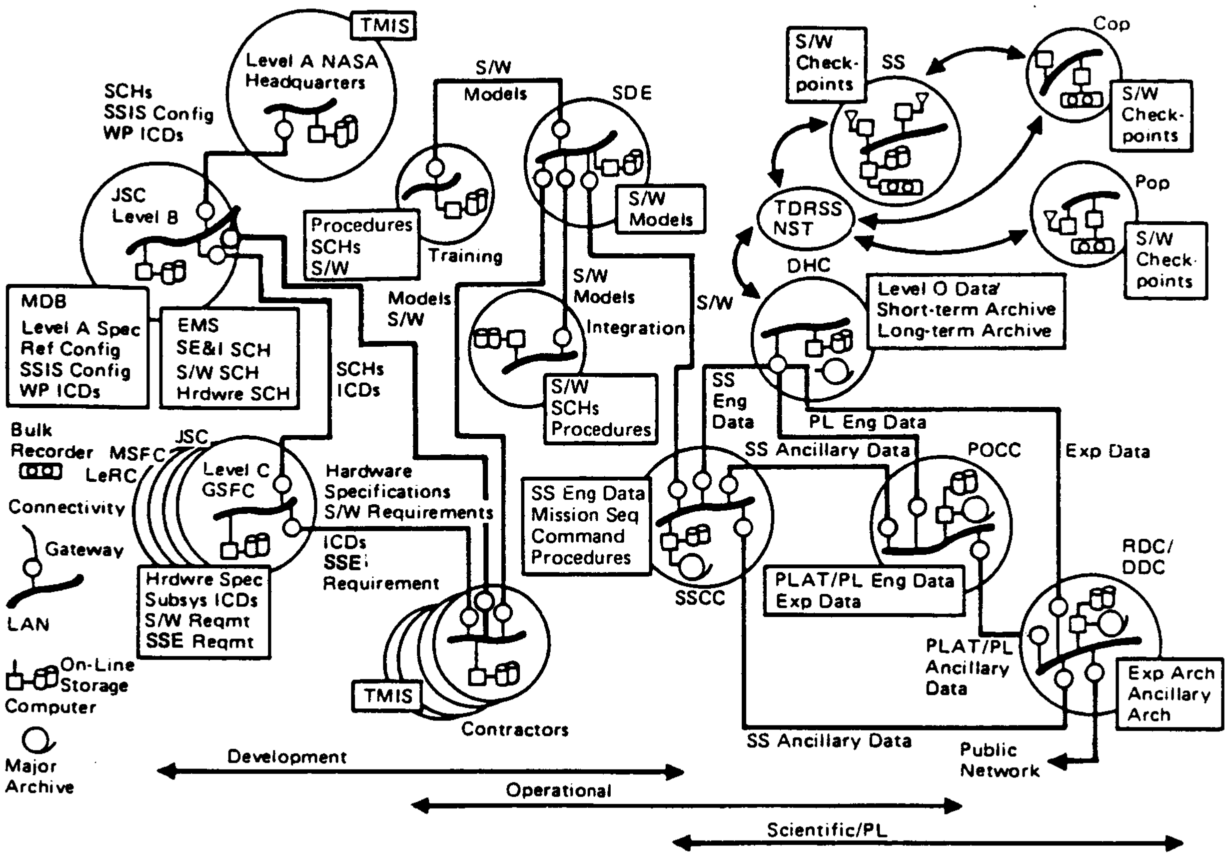


Figure 3.1.1. SSIS Recommended Data Base Distribution

TABLE 3.2.1 DATA BASE SPACE/GROUND DISTRIBUTION

P – PRIMARY OWNER
S – SHARED REPLICATION COPY
* – OPERATIONAL DATA HISTORICAL ARCHIVE

DATA BASE	DATA BASE CONTENT	DISTRIBUTION/ REPLICATION	
		SPACE	GROUND
SSE DB	– SOFTWARE		P
	– MODELS		P
	– TEST SCRIPTS		P
	– RESOURCE SCHEDULING		P
TRAINING DB	– PROCEDURES	S	P
	– SCHEDULES		P
INTEGRATION SITE DB	– SOFTWARE		P
	– INTEGRATION SCHEDULES		P
	– PROCEDURES		P
	– TEST SCRIPTS		P
SSCC DB	– SPACE STATION STATUS	S	P
	– MISSION SEQUENCING	S	P
	– COMMAND PROCEDURES		P
POCC DB	– PLATFORM/PL ENGINEERING DATA		P
	– EXPERIMENT DATA		P
RDC/DDC DB	– SS ANCILLARY DATA ARCHIVE		
	– PLAT ANCILLARY DATA ARCHIVE		
	– FF ANCILLARY DATA ARCHIVE		
SS OPERATIONAL DB	– MANUALS (PROCEDURES)	S	P
	– DAILY SCHEDULES	P	S
	– DIAGNOSTIC SUPPORT	S	P
	– SOFTWARE	S	P
	– CHECKPOINTS	P	–
	– SUBSYSTEM TREND DATA	P	*
	– REAL-TIME DATA	P	*
	– BEFFERED DATA	P	*
COP/POP OPERATIONAL DB	– ENGINEERING DATA	P	*
	– SCIENTIFIC DATA	P	*
DHC DB	– LEVEL 0 DATA		P
	– SHORT TERM ARCHIVE		P
	– LONG TERM ARCHIVE		P

TABLE 3.2.2 SPACE STATION OPERATIONAL DB

P - PRIMARY OWNER
S - SHARED REPLICATION COPY
* - OPERATIONAL DATA HISTORICAL ARCHIVE

PARTITION	PLACE OF ORIGIN	DISTRIBUTION SPACE	DISTRIBUTION GROUND
MANUALS (PROCEDURES)	GROUND	S	P
DAILY SCHEDULES	SPACE	P	S
DIAGNOSTIC SUPPORT	GROUND	S	P
SOFTWARE	GROUND	S**	P
CHECKPOINTS	SPACE	P	NOT NEEDED
SUBSYSTEM TREND DATA	SPACE	P	*
REAL-TIME DATA	SPACE	P	*
BUFFERED DATA	SPACE	P	*

** NOTE 1: THE LATEST VERSION OF SOFTWARE IS ALWAYS RESIDENT IN THE SPACE ODB (I.E., A REQUEST FOR AN OVERLAY DOES NOT TRIGGER A TRANSFER FROM GROUND TO SPACE; OLD VERSIONS ARE AUTOMATICALLY REPLACED UPON RELEASE OF A NEW VERSION, AUTOMATIC REPLACEMENT IF ACTIVE IN AN SDP)

3.2 SPACE/GROUND PARTITIONING

In Table 3.2.1, the SSDS data bases are listed and a distribution between space and ground is suggested. Some elements of the data bases are shared between ground and onboard (e.g., training procedures, Space Station status, ...). What is suggested here is that some segments of the DB's could be replicated in space (i.e., the current version could be copied on request and held in the space ODB partition). That is the ability to retrieve DB files (mainly from the ground) could be provided and these files would be held in the space ODB until another more recent copy was retrieved for a new session. The space in the ODB for the copy would be released as the session is closed.

The selection of the partitions of the DB which could use this method of controlled replication were determined along the following lines of reasoning.

There are two major types of data that are maintained in the operational data base: "realtime data" which is being updated periodically at a high frequency (e.g., sample subsystem data) and static data which is updated very seldom (e.g., software, diagnostic aids, etc.). The realtime data originates in space and some amount must be held there for user interface and subsystem support. There is no need for controlled replication in this case since the sampled data must be delivered to a ground data base for ground support and archiving. In Table 3.3.2, we see that the sampled data partitions are delivered to an archive and do not use the controlled replication method. The other partitions fall into the "static data" category and can use controlled replication for sharing.

The alternative to shared replication is data query by transmission from space to ground and response to the user terminal. In Figure 3.2.1, the capabilities for return and forward links messages are presented. These channel capacities are shared with other communication requirements (voice, video, subsystem periodic data, etc. and therefore all this bandwidth is not available for block transfers). In the shared replication alternative, a block of data is transmitted on the communication links and then no further traffic is on the communication link. Interactions occur between the transferred block and the local terminals. In the remote query alternative, every query results in communication link transmission. It appears that the communication link capacities support the selection of block transfers (for shared replication). There would be an initial delay while the data block is transfered, but then the delays would be minimized since the local ODB would service querys. The partitions of the ODB recommended for sharing replication are all "text" type data (e.g., diagnostic procedures, etc.) and therefore, by the nature of the functions being performed the initial delay appears to be acceptable. If it is determined at a later time that the block sizes are to large for this alternative, some feature in the ODB could be considered which selects between the block transfer and the remote query. This would be a transparent selection process.

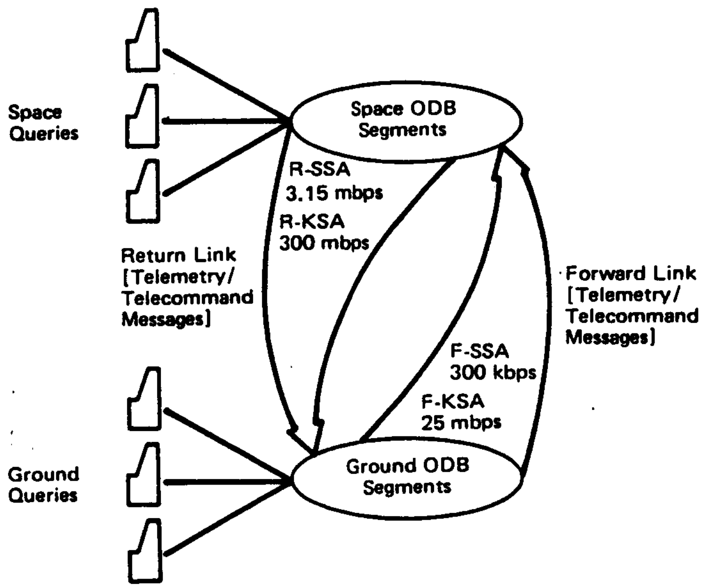


Figure 3.2.1. Operational DB Ground/Space Partitioning

3.3 SSP DB SEGMENT CHARACTERIZATION

The requirements for data base services at each entity is shown in the following table. The characterization of requirements was extracted from reference material in Appendix B of the SSDS A/A option report.

TABLE 3.3.1 : DATA BASE MGMT SERVICE REQUIREMENTS

	FILE SERVER							TEXT PROC	REPORTS				INTERFACE LANGUAGE				SECURITY REQD	ARCHIVE	STATISTICAL FCN
	CREATE	STORE	RETRIEVE	COPY	MERGE	DELETE	UPDATE		CANNED	USER SPEC	PLOTS	GRAPHICS	AD HOC QUERY	INTERACTIVE	REAL TIME	PROCEDURAL			
NASA HDQTRS	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
LEVEL B JSC	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LVL C JSC	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
LVL C GSFC	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
LVL C MSFC	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
LVL C LEWIS	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
CONTRACTOR 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
CONTRACTOR 2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
CONTRACTOR 3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
CONTRACTOR 4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
SSE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
SSCC	X	X	X								X	X	X	X				X	
POCC	X	X	X								X	X	X	X				X	X
RDC	X	X	X															X	
DDC	X	X	X															X	
INTEG SITE	X	X	X																
TRAINING	X	X	X																
SPACE STN	X	X	X								X	X	X	X					
COP	X	X	X																
POP	X	X	X																
DHC	X	X	X															X	

4.0 CONCLUSIONS, RECOMMENDATIONS AND REMAINING ISSUES

It is recommended that the control of all SSDS data bases (content, structure, connectivity, etc) be administered by NASA Level B. Local administrators would be accountable to a DB coordinating authority. The recommendations for subdivision of SSDS data bases and their connectivity is presented in Table 3.1.3 and Figure 3.1.1. It is recommended that the contractors TMIS DB be connected to the JSC Level B DB (containing the NASA partition of TMIS; namely the MDB and EMS) and to the Level C center (containing specifications and ICD's). Other connectivity to support data exchange is presented in Figure 3.1.1.

The recommendations for space/ground partitioning are given in Table 3.2.1. Basically the originating source of data contains the primary data base with controlled replication at remote sites. It is recommended that a limited history of engineering data (i.e., sampled subsystem data) originating in a Space Station be held there for trend analysis and user interface. The realtime data should be delivered directly to a ground data base in the Control Center for archive. Engineering data from other unmanned space elements should be delivered directly to the Ground Control Center for archive. All ancillary data should be archived at the Control Centers, Regional Data Centers (RDC) and Discipline Data Centers (DDC). Space Station ancillary data should be delivered from the SSCC to the POCC's. Experimental data should be archived at the RDC/DDC.

The recommendations for SSDS data base characteristics are presented in Table 4.1. Within each data base the general content is presented and a data structure recommended. In some cases several structures are recommended since the DB contains partitions with different data applications. An example is the SSE data base where the software is in hierarchical data sets but the configuration management is relational.

Table 4.1

SSDS DATA BASE RECOMMENDATIONS

DATA BASE	DATA BASE CONTENT	RECOMMENDATIONS: DATA STRUCTURE	DISTRIBUTION	REPLICATION/ RECOVERY	USER INTERFACE	PRESENTATIONS & REPORTS
SSE DB	- SOFTWARE - MODELS - TEST SCRIPTS - RESOURCE SCHEDULING/ACCT - CONFIG MGMT	- HIERARCHICAL - DATA SETS FOR S/W - RELATIONAL CONFIG MGMT	- DISTRIBUTED DB CONTRIBUTORS - CENTRALIZED MASTER DB - REMOTE MASTER DB COPIES	- MULTIPLE REPLICATIONS FOR SYSTEM AND MEDIA FAILURES	- DIRECTORY QUERY - AD HOC QUERY OF CONFIG MGMT	- HELP PANELS - DIRECTORY PANELS - STANDARD REPORT PANELS
TRAINING DB	- PROCEDURES - SCHEDULES	- FLAT FILE PROC'S - RELATIONAL SCH'S	- CENTRALIZED	- MULTIPLE REPLICATIONS FOR SYSTEM AND MEDIA FAILURES	- DIRECTORY QUERY - AD HOC SCHEDULE QUERY	- HELP PANELS - DIRECTORY PANELS - STANDARD REPORT PANELS
INTEGRATION SITE	- SOFTWARE - INTEGRATION SCHEDULES - PROCEDURES - TEST SCRIPTS	- HIERARCHICAL DATA SETS	- CENTRALIZED	- MULTIPLE REPLICATIONS FOR SYSTEM AND MEDIA FAILURES	- DIRECTORY QUERY	- HELP PANELS - DIRECTORY PANELS - STANDARD REPORT PANELS
SSCC	- SPACE STATION STATUS - MISSION SEQUENCING - COMMAND PROCEDURES	- HIERARCHICAL DATA SETS	- CENTRALIZED - REMOTE REPLICATION ON REQUEST	- MULTIPLE REPLICATIONS FOR SYSTEM AND MEDIA FAILURES	- DIRECTORY QUERY - SAMPLED DATA AD HOC QUERY	- HELP PANELS - DIRECTORY PANELS - STANDARD REPORT PANELS & GRAPHICS
POCC DB	- PLATFORM/PL ENGINEERING DATA - EXPERIMENT DATA	- HIERARCHICAL DATA SETS	- CENTRALIZED - REMOTE REPLICATION ON REQUEST	- MULTIPLE REPLICATIONS FOR SYSTEM AND MEDIA FAILURES	- DIRECTORY QUERY - SAMPLED DATA AD HOC QUERY	- HELP PANELS - DIRECTORY PANELS - STANDARD REPORT PANELS
RDC/DDC	- SS ANCILLARY DATA ARCHIVE - PLAT ANCILLARY DATA ARCHIVE - FF ANCILLARY DATA ARCHIVE	- HIERARCHICAL DATA SETS	- CENTRALIZED - REMOTE REPLICATION ON REQUEST	- MULTIPLE REPLICATIONS FOR SYSTEM AND MEDIA FAILURES	- SFDU DIRECTORY FOR SAMPLED DATA - AD HOC QUERY OF SAMPELED DATA	- HELP PANELS - DIRECTORY PANELS - STANDARD REPORT PANELS
SS O/B DB	- MANUALS(PROCEDURES) - DAILY SCHEDULES - DIAGNOSTIC SUPPORT - SOFTWARE - CHECKPOINTS - SUBSYSTEM TREND DATA - REAL-TIME DATA - BUFFERED DATA	- HEIRARCHICAL DATA SETS FOR TEXT, S/W CHECKPOINTS - RELATIONAL RECORDS FOR SAMPLED DATA (PRIMARY KEY IS TIME	- CENTRALIZED - REMOTE REPLICATION ON REQUEST - GROUND SAMPLED DATA HISTORICAL ARCHIVE	- MULTIPLE REPLICATIONS FOR SYSTEM AND MEDIA FAILURES	- DIRECTORY QUERY FOR TEXT - SOME AD HOC QUERY OF SAMPLED DATA - SFDI DIRECTORY FOR SAMPLED DATA	- HELP PANELS - DIRECTORY PANELS - STANDARD REPORT PANELS & GRAPHICS
COP/POP O/B DB	- ENGINEERING DATA - SCIENTIFIC DATA	- HIERARCHICAL DATA SETS	- CENTRALIZED - GROUND SAMPLED DATA HISTORICAL ARCHIVE	- MULTIPLE FOR SYSTEM AND MEDIA FAILURES	NOT NEEDED (QUERY GROUND DB)	- HELP PANELS - DIRECTORY PANELS - STANDARD REPORT PANELS
DHC	- LEVEL 0 DATA - SHORT TERM ARCHIVE - LONG TERM ARCHIVE	- HIERARCHICAL DATA SETS	- CENTRALIZED - REMOTE REPLICATION ON REQUEST	- MULTIPLE FOR SYSTEM AND MEDIA FAILURES	- SFDU DIRECTORY FOR SAMPLED DATA	- HELP PANELS - DIRECTORY PANELS - STANDARD REPORT PANELS

All the data base entities are recommended to be centralized with the capability to share data by transmitting copies of DB partitioning to remote sites during query sessions. The star of each query session would result in a fresh snapshot of the DB partition being transmitted so intervening updates are be incorporated. This recommendation is made with the caviot that if the partitions blocks turn out to be too large, then the alternative for remote query be kept in reserve.

At each centralized site it is recommended that multiple replications be maintained for system and media failures. The depth of replication should be determined by criticality and established by the DBA.

It is recommended that the user interface to all data bases through directory query. The directory for ancillary data and experimental data should be in Standard Format Data Units (SFDU). The ability to perform ad hoc query on sampled data records should be supported. All DB's should support help panels, directory panels and standard report formats. Graphics presentation should be available in the SSCC ODB and Space Station ODB.

4.1 SPACE STATION OPERATIONAL DATA BASE

The content of the Operational Data Base (ODB) is presented in Table 3.2.2 along with the distribution between space and ground of each major partition. Current estimates of the onboard ODB are as follows:

The DMS must provide storage for 256 Mbytes on on-volatile memory.

90 Mbytes	application program loads
10 Mbytes	checkpoints
10 Mbytes	engineering data
10 Mbytes	procedures
10 Mbytes	schedules
50 Mbytes	telemetry data acquisition
76 Mbytes	growth margin

It is recommended that the onboard operational data base have the structure suggested in Figure 1.5.2.1. This alternative is Alternative 1 in Figure 1.5.2.4.1. A separate ODBMS service would exist in the Core Local Area Network (CLAN) and the Payload Local Area Network (PLAN). These ODBMS's would be homogeneous and communicate to support ancillary data distribution, and other standard core services.

It is recommended that the alternative presented in Figure 1.5.2.3.2 be used for the data acquisition interface to the ODBMS. The subsystems would collect data into records and deliver these records to the ODBMS on a dynamically negotiated basis. (More details in Section 1.5.2.1 and Appendix A) The ODB would support Telemetry Traffic Control (TTC) in building Telemetry Buffer Units (TBU's) for deliver to the communication toggle buffers. The same interface is recommended for PL/EXP except the PL/EXP would deliver data in CCSDS telemetry packet format. The TTC would segment these packets (if necessary) when building the TBU's.

For the build-up of the onboard mass memory configuration it is recommended that Alternative 1 presented in Figure 1.5.2.4.2 be used. In this configuration the SDP/NIU nodes manage local non-volatile memory for the first two flights and then mass storage units are delivered in the first pressurized module (HM1).

The recommended mass memory integration with other DMS elements is presented as Alternative 1 in Figure 1.5.2.4.3. In this configuration the mass storage is on a local bus (serial or parallel to be determined) on the backend of an NIU.

4.2 REMAINING ISSUES

All of the issues mentioned in Section 1.2 still remain open to some degree and the following issues also need to be considered. The matter of integrating text and graphics in DB partitions which contain presentations and reports needs to be addressed.

The compatibility of ground DB segments needs to be considered in light of the recommended DB connectivity.

The concept of a switchable interface to mass store for the buffering of data and then merge in the communication subsystem (as shown in Figure 4.2.1) needs to be evaluated. This is the proposed interface to the communication node to get buffered data merged with realtime data.

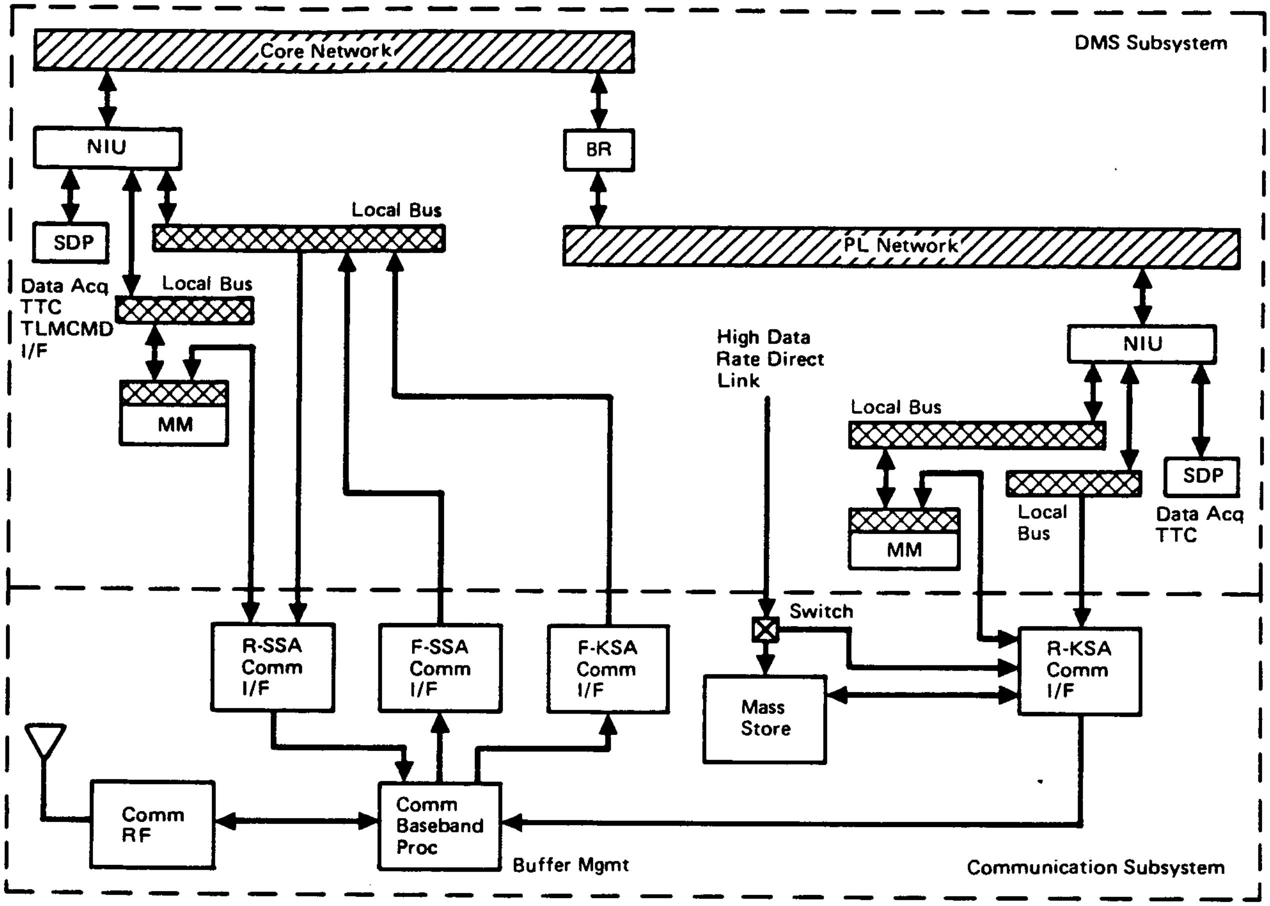


Figure 4.2.1. Communication Gateway

5.0 REFERENCES

"Space Station Data Base Management Study", Computer Technology Associates, Inc., November 18, 1983

APPENDIX A
DATA ACQUISITION CONCEPT

This Appendix expands on the data acquisition service concept. Subsystems could initiate the storage of current and historical data by sending a request for service to the ODBMS. The service request could be to a standard mail box (with multiple sockets to service concurrent requests) with the following layout.

Figure 1.5.2.1.2 DATA ACQUISITION REQUEST FORMAT

REQUESTORS_MAILBOX_ADDRESS	
PARAMETER_LENGTH	RECORD_LENGTH
PERIODIC/APERIODIC	PERIOD
HISTORY_REQUEST	HISTORY_LENGTH
UNIQUE_RECORD_NAME	

The REQUESTORS_MAILBOX_ADDRESS is an object name where the ODBMS can request further information about the subsystem storage requirements. The PARAMETER-LENGTH indicates to the ODBMS how many parameters are in the record and the RECORD_LENGTH indicates the number of bytes in the record. The Periodic/Aperiodic flag indicates if the record is to be sent to the ODBMS on a periodic basis or just once. PERIOD specifies the period in seconds. If the HISTORY_REQUEST flag is set, this indicates that back values are to be saved. If back values are to be saved, the number of back values is indicated in HISTORY_LENGTH. The UNIQUE_RECORD_NAME (URN) is the name assigned by the subsystem to identify the records that will be sent to the ODBMS.

The ODBMS then sends a message to the requestor's mailbox address and requests a record definition to be returned. The record definition contains the subsystem parameter object names and the number of bytes for each parameter (field length). The ODBMS then stores this data in a parameter directory containing all unique object names (UON) available from the ODBMS. (See Figure 1.5.7.1.5) Each object name is limited to 32 characters.

Figure 1.5.2.1.3 SUBSYSTEM PARAMETER DEFINITION

SUBSYSTEM-OBJECT-NAME-1	Field - 1
SUBSYSTEM-OBJECT-NAME-2	Field - 2
.	
.	
.	

The ODBMS sets up a mailbox to receive the data record from the subsystem and also establishes a memory space for the historical data on mass storage. The historical data is maintained in a circular file. Each record from the subsystems has the following format:

Figure 1.5.2.1.4 RECORD FORMAT

UNIQUE - RECORD - NAME
UON 1
UON 2
.
.
.

Figure 1.5.2.5 HISTORICAL RECORD FILE

	RECORD (K-1)	
	.	
	.	
	.	
Curr. Record Pointer	RECORD (2)	'N' Records
	RECORD (1)	In File
Next Record to be Overwritten	RECORD (HISTORY-LENGTH)	
	.	
	.	
	.	
	RECORD (K)	

When the records received reach the HISTORY-LENGTH, then the pointer wraps around and several alternatives exist. If an archive history file is to be maintained for this subsystem record, then at each pointer wrap, the total history file could be telemetered to a ground data base for archive storage. The ground data base would be informed of the data content by a similar mechanism to the subsystem interface to ODBMS. Alternatively, each record could have been telemetered immediately that the current record was updated by the subsystem for ground operational DB support.

The ODBMS could then accept requests to retrieve data from the parameter catalog on an UON basis. The current value can be requested or any number of historical records up to HIST-LENGTH.

Figure 1.5.2.1.5 ODBMS PARAMETER DIRECTORY

UON_1	$HISTORY-RECORD-LOCATION_1$	CURRENT-RECORD-POINTER
UON_2	$HISTORY-RECORD-LOCATION_2$	CURRENT-RECORD-POINTER
.	.	.
.	.	.
.	.	.

System Integration Test & Verification (SITV) Trade Study

1.0 Trade Study Definition

1.1 Purpose of Trade Study

To identify the preferred options for the Integration, Test and Verification of the Space Station Data System (SSDS) elements, consistent with the SSP mission and programmatic goals.

1.2 Background

1.2.1 General

The operational SSDS will consist of Ground and Space segments, each designed to meet the functional allocation of the SSDS requirements, and linked, at least initially, via the TDRS system. The integration, test and verification effort for these segments, both individually and in combination encompasses a number of significant options to be addressed in this trade study activity.

A reference model for the over-all effort is provided in Figure 1. The intent of this figure is to identify the significant Integration and Test levels to be addressed while also providing a top-to-bottom chronology. As shown in the figure, it is prerequisite that the Ground Segment be operational to fully support pre-launch and on-orbit activities of the Space Elements. The Ground segment will interface with existing/modified institutional facilities to provide the data/command management (distibution, processing, archiving, etc), mission control and scheduling, and configuration management functions. It is anticipated that the Ground segment will utilize primarily commercially available equipment that can be emplaced and activated with few, if any, difficulties. Target, or functionally representative hardware will be available, based on well supported commercial product lines, to accommodate software development requirements.

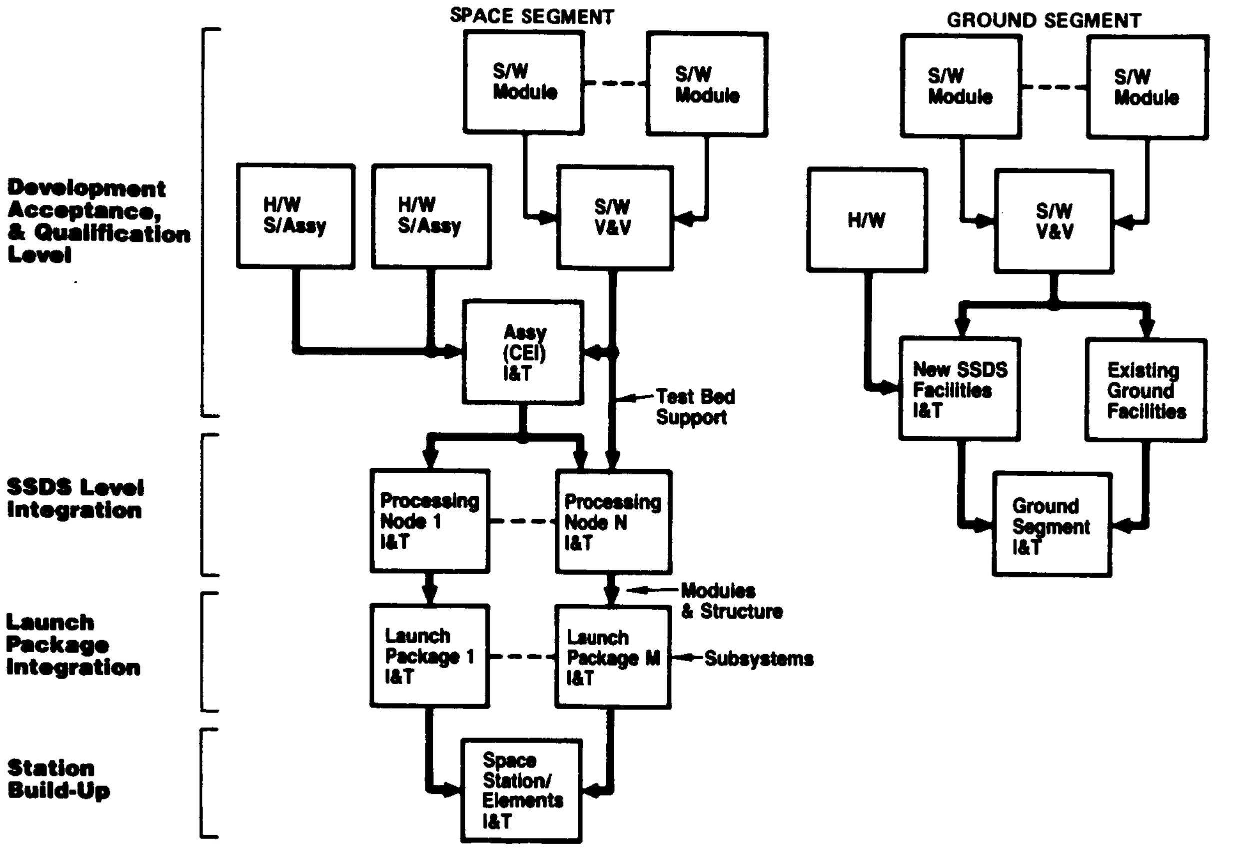


Figure 1. SSDS Integration & Test Overview

The space segment acquisition presents considerably higher technical risks because of the need for orbital assembly and activation, the limited Station accessibility, and the space environments. Preliminary concepts for the On-board SSDS design have proposed a distributed, networking configuration; it is anticipated that processing nodes (combinations of processors, network interface units, and mass storage devices) will be embedded into the various modules and structural elements of the Space Station. These nodes, supported by man-machine-interfaces (workstations), and interconnected by an appropriate network design with an interface to the Communication and Tracking sub-system, must support the full functionality of the IOC Station yet must be compatible with a coherent and efficient build-up phase.

The current build-up concept, as discussed in Task 1, Section 4.4.3, proposes at least seven launch packages (driven by NSTS cargo weight and volume compatibility) to be boosted to orbit in a logical sequence for incremental assembly into the IOC Station. As depicted in Figure 1, it is anticipated that the On-board SSDS hardware will be integrated into its host launch package and checked out prior to launch.

The acquisition phase environment for the SSDS will be one in which its H/W and S/W products are procured/developed and delivered by multiple sources. These deliveries may be chronologically staggered to match the build-up sequence and to reduce peak funding requirements. The concept of staggered deliveries may impact apparent goals to verify all Space Segment flight interfaces prior to launch however in some cases this goal may prove to be less than practical and in other cases may be unnecessary. Payload interfaces, for example, may fall into the latter category on the basis that such interface must be standard/common; during ground integration testing of the on-board system, a generic payload simulation should be sufficient, from an SSDS perspective, to establish the interface compatibility. A symmetrical verification will suffice for the general payload.

The factor of multiple contractors adds considerable complexity to the system integration effort, particularly when sub-systems may be distributed, not only across different modules and structural elements but also across the contractual work packages. Commitment to an effective program of standardization and commonality will significantly reduce the number of unique hardware configurations and interface protocols. Any resulting penalty in operational efficiency will be more than offset by a cost payoff in the form of reduced development, certification, test equipment and fixtures, and spares requirements. The standards however must be sufficiently defined to preclude interface incompatibility between different contractor implementations. Standardization on specific programming and user interface languages will provide a second level of efficiency through, a) minimization of software support requirements, b) establishment of source and object code libraries, and c) reduction of expertise requirements.

In summary, the Integration, Test, and Verification and implemented procurement strategies will be interdependent; cost optimization must, in fact, be a marriage of options from both.

1.2.2 Ground Segment Concepts

It is recognized that there are significant design/configuration issues associated with the SSDS ground segment. For example, incorporation of existing H/W and S/W capabilities with differing interfaces and protocols must be accommodated. Integration and Test concepts must be considered within the systems engineering tasks however the primary obstacle will be that of the design. Problems will inevitably occur, however, the over-all acquisition will be relatively routine since:

- There are few procurement constraints; environment/qualification is not an issue, and there are few, if any, critical weight, power or volume limitations

- Equipment/facility accessibility is not a problem.

- The major SSDS elements will be dedicated and can be integrated/activated with minimal operational interference with existing facilities.

Since no significant Integration and Test issues for the Ground Segment have been identified, this segment will not be specifically addressed further in this trade study effort.

1.2.3 SSDS Space Segment

The typical space flight hardware has virtually no post launch accessibility and must be in at least a near-operational configuration at launch since this hardware typically has minimal automated or remote reconfigurability. Conservative test programs are therefore dictated that provide comprehensive demonstations of operational effectiveness and suitability, and include full "all-systems" integration testing on the operational configuration. Following comprehensive all system testing, the integrity of flight interfaces must be maintained (or re-established) through pre-launch checkout and flight.

The Space Station, in contrast, will be incrementally boosted to and assembled on orbit. It will be accessible on at least a limited basis during build-up (and man-tended phases) and will be fully accessible as a manned facility. These differences imply that individual launch packages need not be constrained to an operational configuration for launch. Also, the noted accessibility implies a maintainability such that a large variety of equipment problems identified during build-up and activation can be corrected on orbit. It is therefore concluded that:

- Hardware susceptible to the NSTS environments yet compatible with the Station environments could be provided with special handling/packaging for NSTS launch/re-entry operations, and,

- Reduced MTBF requirements may be tolerable, particularly with the NASA imposed fail op/fail safe/restorable design requirements.

Strategies to reduce the rigorous environment/interface compatibility tests and repetitive performance demonstrations are therefore viable to cost optimize the Integration, Test and Verification against acceptable risk profiles. It is this theme that is pursued in this trade activity.

1.2.4 Test Definitions

To clarify the discussions of the subsequent sections, test definitions for the standard test sequence are provided in Appendix A of this study.

1.2.5 Acceptance and Qualification Test Concepts

The Task 2 System Test, Integration, and Verification options paper discussed the following acceptance and qualification test deviations to the 'standard' industry approach:

a) Deferment of selected sub-assembly functional and environmental testing to the next (assembly) levels.

b) Deletion of selected (e.g. thermal vacuum) environmental tests during module acceptance testing, and,

c) Modification of traditional certification (qualification) testing profiles (levels and durations) to support protoflighting, thus minimizing non-flight hardware costs.

These deviations are consistent with the above theme of reduced conservatism and are thus the preferred approach almost by inspection; option (c), in fact, is effectively a given. Since these deviations can only be discussed from a relatively high level and on the basis of generic hardware, they are not readily decomposed into sub options to be traded. Therefore, acceptance and qualification testing will not be addressed further in this study activity.

1.2.6 Verification Concepts

As indicated by the Appendix A definition, the System Verification effort will be distributed across all levels of the ground testing; in addition, since some Space Station operational testing may not be practical or feasible in a 1g environment, the verification program must be completed during the on-orbit activation sequences.

The goals of the verification program are to not only insure design compliance but to efficiently, and cost effectively, provide early and comprehensive identification of discrepancies. Design compliance must address operational suitability requirements, e.g. reliability, safety, and maintainability, etc. in addition to the normal functional, performance, and compatibility requirements. The typical verification program therefore overlays and expands on the normal test sequence of the first production units. In general, however, the verification activities adhere so closely to the structure and policies of the underlying tests that separate issues with respect to depth and degree of testing, facilities requirements, and costs can not be differentiated. Options/trades for the verification effort have, therefore, not been generally addressed.

The single exception is the performance of an SSDS end-to-end (Space and Ground) verification. Such a verification appears to be favored to insure full end-to-end compatibility prior to launch. The concept implies interconnection/assembly of several launch packages to provide an operational capability such that the Ground System can operation and monitor selected 'on-orbit' sub-systems and payloads through the TDRSS link. This option may be unwieldy however with respect to the Space Segment because of the assembly/tear down operations, the increased facility requirements, and the potential impact on the TDRSS/Nascom resources. A piece-meal, more independent approach may be more viable and still provide sufficient confidence. This issue is discussed and the options traded in Section 3.0.

1.2.7 Integration/Test Concepts

The integration/test process assembles and links hardware and software entities to form partial or complete systems with specified functional capabilities which are then verified. This activity will generally be accomplished through incremental addition of products until a required level of functional capability is achieved and verified. The definition of these products may vary widely depending on procurement packages/contracts and will impact the development/integration methods. Generally, these products can be characterized as:

a) S/W Packages - separately developed software packages that have been tested in a 'stand-alone' mode using a target machine, emulator or functional simulator,

b) Hardware Components - separately procured/developed hardware items that have been previously acceptance tested and certified. It is generally assumed that the integration of separately procured computers and software packages is accomplished prior to integration and not included in this definition. Examples are hardware items such as time frequency generators, network media, and NIU's, or,

c) Integrated Hardware/Software - separately developed "subsystems" that include software already integrated with internal hardware components, i.e. computers, mass storage, etc. When multiple computers are required for a 'subsystem' entity, it is assumed that the same level computer integration testing is performed prior to integration. However, full integration of subsystem computers may become a SITV function depending on availability of network hardware to the subsystem contractor.

One of the more technically challenging aspect of the On-Board SSDS design described earlier will be the distributed operating system, (DOS). The DOS will be developed in software modules corresponding to each of the processing nodes and software interfaces will be verified using either target hardware or emulators as indicated in Figure 1. An integration of hardware and software will occur at the next (SSDS) level; however, there appear to be two basic approaches. One option is to perform a full sub-system test utilizing a 'test bed' to interconnect all processing nodes. A second approach would be a segmented approach, testing each processing node individually and simulating the remainder of the subsystem. The key issue of these options is whether a full verification of the distributed operating system (DOS) is necessary at this relatively low integration level.

At the next (launch package) level, the sub-systems and structural elements including the SSDS will be assembled into their functional elements, primarily associated with launch packages. Clearly, each individual package will require a comprehensive Integration/Test effort, however, there is also some consideration for a more inclusive pre-launch integration of the over-all Station. The available options, analogous to those at the SSDS level, are:

1) A "segmented" approach wherein the integration is limited to the hardware and software associated with each launch package; the interfaces to the rest of the Space Station and ground would be simulated, and,

2) An "all systems" integration of the full Station wherein all subsystems and structure are assembled/interconnected to the maximum practical extent to demonstrate the 'full' SSDS capabilities.

Clearly, the Station environments for the 'all systems' approach will limit structural deployment and some sub-system functionality, however there is precedence and program benefit for such large 'all systems' exercises.

Growth, with respect to the SSDS will provide vertical and/or horizontal expansion of capabilities, including added autonomy. Effective systems engineering will define the appropriate interfaces for the over-all system vertical/horizontal hierarchy such that hardware and software entities can be added and replaced with minimal impact to the remaining 'structure'. The on-orbit Integration/Test effort will be a sequence of hardware (BIT) verification, interface compatibility checks, and functionality verification. There must be some ground preparation, however, to minimize the risk of the on-orbit activity. The options include:

a) utilization of relatively high fidelity simulation or production spares if available, and,

b) remote integration to the existing operational configuration utilizing the TDRSS links.

The above integration/test and verification concepts are refined and traded in the following sections.

1.3 Issues

The issues to be addressed in this study activity are:

- What ground integration effort should be performed on the isolated (on-board) SSDS?

- What ground integration effort should be performed on the launch packages/Space Station (from the SSDS perspective) prior to launch?

- What pre-launch SSDS end-to-end verification is appropriate?

- What pre-launch integration effort should be performed on "growth phase" elements?

1.4 Trade Study Criteria

The full set of criteria parameters and definitions for the subsequent trade analyses is tabulated below. The criteria listed is utilized for each of the trade analyses and has been assigned a weighting as shown in the tabulation. This weighting, as discussed in the Section 2.0 methodology, is an assessment of the relative impact of the parameter to the project success.

- Cost (Weighting - 30%)
    - New Facilities - Cost of facilities if required to support the option.
    - Manpower - The manpower requirements of the particular option
    - Duration - The relative time period required to complete the option
    - Test Equipment - the costs of test equipment including fixtures and software required to support the option
    - Schedule (Weighting - 25%)
        - The impact of the option on the overall program schedule
    - Risk (Weighting - 25%)
        - Technical - The relative technical difficulty/feasibility in completing the option requirements
        - Program - The potential impact to program achievability based performing or not performing the option.

- Suitability (Weighting: 20%)

  - Test Efficiency – The relative efficiency of the option, i.e. the effort expended vs the probability of detecting problems.

  - Safety Considerations – The relative personnel and equipment safety in the performance of the option testing.

2.0 Trade Study Methodology

For each of the trade areas, the following methodology has been applied.

1) Fully characterize the options: Each option will be characterized as fully as possible to allow a fine grained assessment corresponding to each parameter of the criteria.

2) Select an appropriate set of evaluation parameters: This set has been provided in Section 1.4.

3) Provide weighting factors for each evaluation parameter: A weighting factor has been assigned to each parameter of the criteria set based on its relative impact to the project success. Cost, for example, is a relatively high impact parameter and will be assigned a higher percentage weight.

4) Provide a numerical assessment for each option: A numerical assignment (0–10) will be entered in each option column, corresponding to each parameter of the criteria. This assignment provides a relative estimate of the suitability or effectiveness of the option based strictly on that parameter. A "10" indicates an excellent assessment; a "0" indicates a total deficiency. Note that inverse parameters, such as risk are inversely rated, i.e., higher costs and risks generate lower ratings.

5) Score and rank the options: The parameter assignment times its weighting provides the option score for that element of criteria. The preferred option is identified by the largest criteria score sum.

6) Perform sensitivity analysis: An analysis will be performed to identify the key decision drivers.

7) Re-evaluate individual trade activities: Each trade study will be evaluated to determine whether the results are reasonable and expected, to resolve and perceived inconsistencies, and to eliminate potential coupling of dependent issues.

3.0 Trade Study Discussion and Results

3.1 Ground Integration Effort for the SSDS

3.1.1 Discussion

As indicated earlier, the on-board SSDS will be a distributed, networking design utilizing processing nodes to support the sub-system requirements and the separable functions of the Data Management System. It is clear that the Distributed Operating System (DOS) must itself be subjected to exhaustive validation and verification, however, it is not as clear that the total onboard SSDS must be tested as a complete entity. The issue is what testing is required at the SSDS sub-system level to verify its readiness for subsequent integration efforts. The options noted in Section 1.0 are, 1) a segmented, individual processing node Integration and Test, and 2) a full system integration.

For the segmented option, the integration/test would be essentially limited to the hardware and software associated with each individual processing node. The mechanical interfaces for the hardware would be simulated using fixtures that also supply electrical power and thermal control. The electrical and logical interfaces to the remainder of the SSDS (including the DOS) and sub-systems would be provided by simulation. This simulation could also be of benefit to the Verification Program since interface parametrics (voltage, impedances, timing) could be varied to demonstrate processing node compatibility margin. Appropriate diagnostic programs and stimulus would be provided to each processing node to verify its built-in test, fault detection, reconfigurability and performance. The response and output data from each node would be analyzed to insure it functionality.

The benefits of this option are the reduced facility requirements, since much of this simulation and fixtures would be common to each node. Also, this approach could more easily support a staggered development/delivery schedule that was 'launch package' oriented.

The obvious disadvantage to this approach is the higher program risk in deferring the full integration to a higher level (possibly on-orbit) where detected design deficiencies or incompatibilities will have a more severe impact.

The second option performs a full integration/test of all On-Board SSDS hardware and software. A test bed approach is anticipated to accommodate requirements for power, thermal management, etc. The complete local area network (LAN) connectivity would be provided and all configurations, modes and automation/autonomy of the system could be demonstrated against diagnostic data/command traffic scenarios. Associated sub-system, Payload, sensor/effector interfaces would be simulated. The test requirements, procedures, and facilities would all be more complex; however, this option minimizes SSDS functionality risks at the next integration level.

3.1.2 Criteria Evaluation

The criteria parameters associated with these options are briefly discussed in the following paragraphs.

- Cost

It appears that option 1 will generate the lower cost. Fixturing will be required for the mechanical, electrical, and logical simulation of the processing node interfaces however, fixture(s) may be common for many, if not all, of the nodes. The simulation effort, i.e. subsystem and remaining SSDS interfaces, should not be major and may in fact be part of a coherent test aid complement provided for the development contractors.

The manpower requirements cannot be differentiated; option 1 may require a fewer people for an extended period while option 2 would require a shorter period with but with perhaps a higher personnel count and more complex documentation.

- Schedule

Option 1 would provide the more compatible schedule with the staggered launch package flight schedule. Also this approach provides an inherent flexibility in that testing could shift to another processing node if the node under test failed and required some time to disposition.

- Risk

The technical risk would perhaps be somewhat higher with option 2 due to the larger set-up requirements but is not a key discriminant in the performance of either option. The program risk is higher with option 1 since actual (functional/logical) interfaces will not have been verified and the distributed operating system will not have been fully demonstrated prior to proceeding to the next integration level.

- Suitability

Option 2 is clearly more suitable since the actual system interfaces and functionality is test with a minimum of simulation. Noted discrepancies will therefore, in general, be real and not by products of the simulations. Safety is not a concern for either option.

3.1.3 Results

As shown in Table 3.1 - 1, the "full system" option is preferred. The sensitivity analysis shows risk to be the key evaluation factor.

3.2 Ground Integration Effort For The Launch Modules

TRADE STUDY TITLE: SSDS PRE-LAUNCH INTEGRATION EFFORT

CRITERIA	WEIGHT	OPTION 1: EVALUATION	TOTAL	OPTION 2: EVALUATION	TOTAL
COST	30	8	240	6	180
SCHEDULE	25	8	200	6	150
RISK	25	3	75	9	225
SUITABILITY	20	7	140	7	140
TOTALS:	100		655		695

TABLE 3.1 - 1

3.2.1 Discussion

As discussed earlier, the Space Station design must accommodate separable launch packages for incremental boost to orbit and assembly. It is anticipated, however, that each package will be fully integrated on the ground as indicated in Figure 1, i.e. corresponding SSDS segments will be installed/tested and will remain part of that launch package. The actual launch configuration of these packages will, however, be a compromise based on Orbiter Cargo Bay volume and weight constraints, the goal to minimize EVA time during build-up, and special handling requirements for any launch environment susceptible hardware.

It is anticipated that this launch package level integration will occur at a KSC facility to minimize subsequent handling prior to launch and because of potential use of existing facilities.

Like the SSDS level integration activity, there are two primary options on the Space Station plane. The first is the segmented approach, where in the integration is limited to individual launch packages. The second option is that of a full 'all-systems' ground integration/test effort.

For the first option, all hardware and software, electrical power, thermal management, ECLSS, communications, etc. associated with the launch package will be implaced and activated with fixturing and simulation provided to duplicate the interfaces of the remaining launch packages. This approach has some significant advantages in that:

- Facilities and manpower requirements are minimized, and,
- It accommodates a schedule of staggered development/deliveries that will in all likelyhood, more closely match NASA fiscal funding plans.

The primary disadvantage of this option is that the actual interfaces and global functionality verification is deferred to the On-Orbit integration activity where discrepancies can result in serious program pertubations.

For the second option, all launch packages will be assembled/interconnected using special fixtures, extension cabling, etc. Although some structural deployment and sub-system functionality could not be fully demonstrated in a 1g, ambient pressure, ambient temperature environment, considerable confidence can be gained in exercising the sub-systems/launch packages together. This option would not only support full checkout of operating modes but would also support crew training and preliminary development of crew schedules and mission timelines.

The disadvantages of this second approach are the requirements for additional handling, massive facilities, more complex test documentation, greater manpower and inherent inefficiencies.

3.2.2 Criteria Evaluation

The criteria associated with each of the options is briefly discussed in the following paragraphs.

- Cost

Option 1 would require the lower costs because of the lesser facility requirements, and more manageable manpower requirements.

- Schedule

Option 1 is considerably more compatible with the over-all program and allows a staggered integration effort that aligns with the build-up sequence. This approach would allow staggered development and/or delivery of launch package products that would be more compatible with NASA fiscal funding plans.

- Risk

• Option 1 represents a higher program risk because of the delayed/deferred assembly and test of the actual interfaces and the potential of discovering deficiencies and/or incompatibilities on orbit. Option 2 presents a higher technical risk in attempting to assemble and test all launch packages.

- Suitability

Option 2 is less efficient since inevitable problems with any elements (launch packages) will result in test downtime. In the segmented approach, there is the potential of reconfiguring to another launch package (being prepared in parallel) for testing. The necessary structural complexities and facility support requirements will generate somewhat greater hazards for the flight hardware and test crew.

3.2.3 Results

As shown in Table 3.2-1, the segmented approach is preferred. Sensitivity analysis show cost and schedule to be the key discriminants.

3.3 Pre-Launch End-To-End SSDS Verification Effort

3.3.1 Discussion

The Space Station Data System represents considerable complexity, not only in the On-Board functionality but also in the data and command transport between the payload/experiment on-orbit and the customer on the ground. The data/command flow paths include the On-Board LAN, the ground WAN and the intervening TDRSS/Ground Station link. The end-to-end transport must support packetized data formats (encrypted as required), error protection techniques,

TRADE STUDY TITLE: LAUNCH PACKAGE PRE-LAUNCH INTEGRATION EFFORT

CRITERIA	WEIGHT	OPTION 1: EVALUATION	TOTAL	OPTION 2: EVALUATION	TOTAL
COST	30	9	270	5	150
SCHEDULE	25	8	200	5	125
RISK	25	5	125	9	225
SUITABILITY	20	8	160	6	120
TOTALS:	100		755		620

TABLE 3.2 - 1

flow control techniques, and distribution based on packet header addressing. Verification of the data transport has two primary options: 1) a piece-meal approach that verifies sections of the transport path independently and 2) an integrated end-to-end approach.

Option 1 relies heavily, of course, on simulation and minimizes impact on the institutional facilities. The On-Board verification will utilize simulation to provide the desired diagnostic data to the inputs of the element (launch package) under test to simulate sub-system, payload and DMS data/commands; the returned (forwarded) data/commands will be analyzed to insure the proper handling.

The On-Board Communication & Tracking (C&T) Subsystem/TDRS interface is critical. This interface will require comprehensive checkout to insure S-Band and K-Band compatibility and at some point, bit error rate (BER) tests will be required. The TDRSS has compatibility test capabilities available via permanent and mobile van systems that can utilize TDRSS ground simulation support and also provide direct links to the TDRS. Some of this checkout may be performed to the C & T sub-system level and/or at the prelaunch Space Station level.

The SSDS Ground segment can demonstrate its processing, storage, and distribution capabilities through insertion of diagnostic data into the head end of the system (Ground Station) either directly or via a 'loop back' capability to TDRS, and monitoring the subsequent data processing and distribution activity.

The intent of option 2 is to perform an end-to-end verification of the combined paths in as close to operational configuration as possible. For this approach a TDRS SA antenna would be slewed down to the C&T antennas to provide what would normally be the 'space-space' link, as depicted in Figure 2. The TDRSS/Ground SSDS segments would assume normal operational configurations.

It is recognized, however, that there may be severe limitations in assembling the total Station as discussed in Section 3.2.1. In the minimum case, the 'Station' may consist of only the Comm & Tracking sub-system and its

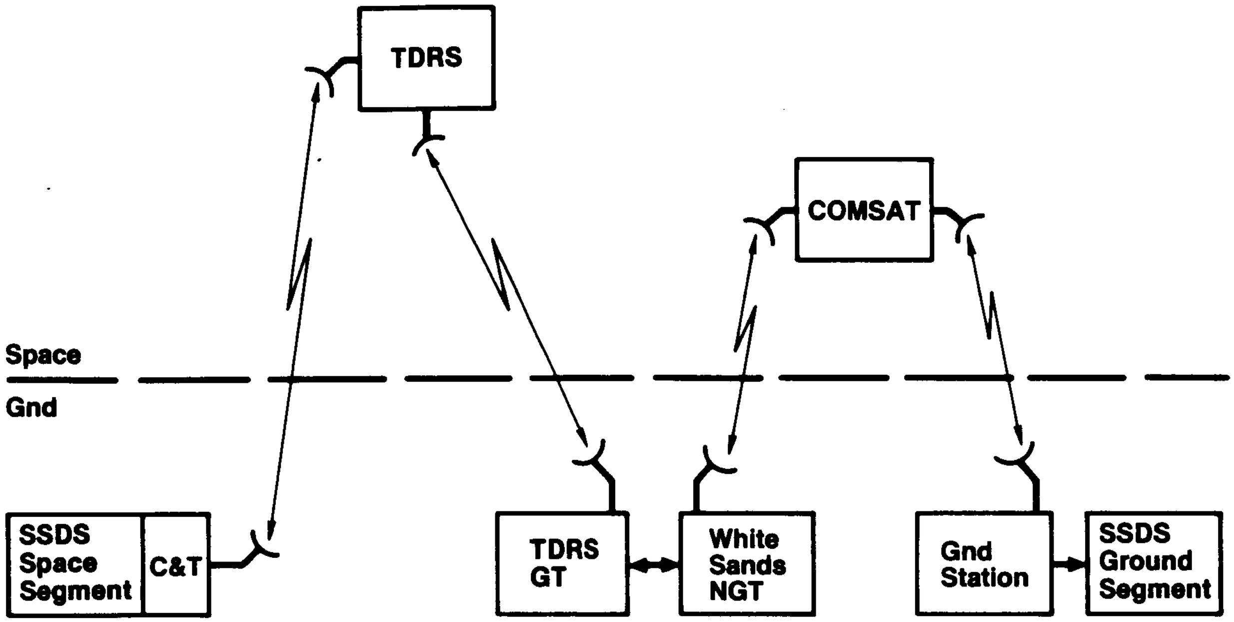


Figure 2. Prelaunch Gnd-to-Gnd Verification

associated launch package(s) with some interfacing DMS elements. The remainder of the Station, (as required), platforms and payloads, would, most likely, be simulated. Another difficulty is that the operational C&T antennas and their supporting trusses may not be deployable in the 1g environment. Thus, non-flight antennas may be required to link to the TDRS. In summary, although there is some added confidence to be gained, ground verification of the end-to-end system has some dis-advantages in that:

- the full end-to-end capability is not practical; much of the On-Board SSDS would be simulated.

- Comm & Tracking Sub-system antennas/mounts are anticipated to be a non-flight configuration.

- this option may impact TDRSS if allocated Space Station resources are not in place, i.e. additional TDRS's, and Ground Station.

3.3.2 Criteria Evaluation

The criteria associated with these options are discussed in the following paragraphs.

- Cost

Option 1 testing will, in all likelihood, be performed in any case which categorizes all of the Option 2 costs as additional.

- Schedule

Option 1 provides more schedule flexibility since the ground and space paths could be verified independently.

- Risk

Technical risk is not a discriminant for either option. There is a decrease in program risk with the performance of Option 2.

- Suitability

Option 2 is considered to be less efficient based on the magnitude of the effort and coordination required to perform the test. Safety is not considered an issue.

3.3.3 Result

As shown in Table 3.3-1, the segmented approach is preferred. Sensitivity analysis shows cost and schedule to be the key discriminants.

3.4 Pre-Launch Integration Effort For Growth Phase Elements

TRADE STUDY TITLE: SSDS PRE-LAUNCH END-TO-END VERIFICATION EFFORT

CRITERIA	WEIGHT	OPTION 1: EVALUATION	TOTAL	OPTION 2: EVALUATION	TOTAL
COST	30	9	270	6	180
SCHEDULE	25	9	225	6	150
RISK	25	5	125	9	225
SUITABILITY	20	7	140	7	140
TOTALS:	100		760		695

TABLE 3.3 - 1

3.4.1 Discussion

Growth phases are planned for the Space Station/SSDS in support of larger complements of payloads/experiments. This growth will result in additional structure, HAB/LAB modules and over-all data/command handling capability. Physical integration of the additional hardware and software with the existing Station must necessarily be performed on-orbit, however, there are options for ground activity in preparation for this integration. Program policies cannot be predicted, however, a high fidelity simulator/mock-up, provided on previous programs, is not anticipated. This assumption removes the possibility of a comprehensive ground integration. Instead, simulators and fixtures utilized in the IOC acquisition phase will be available/modifiable for use. There are, however, options for verifying the functional/logical interfaces of the growth elements.

The first option employs the approaches and lessons learned from the IOC acquisition experience through the use of simulators to verify the functional/logical interfaces of the new elements independent of the existing operational Station. The second option is to utilize the TDRS link to more directly verify the interfaces to the Station.

Option 1 needs little discussion since it has been addressed at length earlier in this paper.

Option 2 provides an (indirect) interface with its associated Station elements. From a logical perspective, this approach provides an advantage in that simulation errors are not involved, however, the link delays may result in severe disadvantages. As noted earlier, the integration effort is presumed to occur at KSC, therefore the multi-path link from KSC to the Space Station and return, could involve delays of several seconds which may impact the test feasibility. This option has the additional dis-advantages that Station configuration/scheduling pertubations would be necessary thus potentially impacting planned operations, and the additional TDRSS traffic could be an impact to the Station and other projects relying on the TDRSS resources.

3.4.2 Criteria Evaluation

The trade study parameters associated with these options is discussed in the following paragraphs.

- Cost

The activities of option 1 would be performed to a large extent whether in preparation for option 2, thus the option 2 costs (man-power, TDRSS, WAN) must be considered additional.

- Schedule

Option 2 would be dependent on the Station and TDRSS scheduling where-as option 1 could be performed independent of any ongoing operations.

- Risk

There is some risk to the option 2 approach in that identified discrepancies could impact the Station. Option 2, if successful however provides a lower over-all risk to the success of the integration.

- Suitability

Suitability is not a discriminant for either option.

3.4.3 Results

As shown in Table 3.4-1, the independent integration approach is preferred on all criteria.

TRADE STUDY TITLE: GROWTH ELEMENTS PRELAUNCH INTEGRATION EFFORT

CRITERIA	WEIGHT	OPTION 1: EVALUATION	TOTAL	OPTION 2: EVALUATION	TOTAL
COST	30	9	270	7	210
SCHEDULE	25	9	225	7	175
RISK	25	8	200	7	175
SUITABILITY	20	7	140	4	80
TOTALS:	100		835		640

TABLE 3.4 - 1

Appendix A – Testing Sequence Definitions

DEVELOPMENT – Engineering evaluation tests of various integration levels of H/W and S/W products. The effort is intended to assist design engineering in evaluating/validating proposed design solutions. This testing is not generally subject to the rigors and documentation formality associated with production flow testing unless, (consistent with the protoflighting concepts), potential mission operational hardware is utilized. Specific NASA Test Beds will be available to support development tests.

CERTIFICATION – Effectively synonomous with Qualification testing, this effort includes those tests and analyses required to demonstrate that design, materials and components, and manufacturing processes will perform in the mission operational environment. Testing generally consists of functional tests in conjuction with environmental exposures to profiles more severe than those projected for the mission. Analyses may substitute for tests to reduce costs and support protoflighting when product and environments can be adequately modeled.

ACCEPTANCE – Testing performed generally at vendor facility to assure that the equipment meets delivery requirements and to demonstrate a readiness for the next integration level. Includes functional performance and environmental exposures to demonstrate immediate capabilities of specific hardware and to screen out faulty components and workmanship not detectable through inspection techniques.

SOFTWARE VALIDATION/VERIFICATION – This effort, performed by the vendor or by an independent agency, is a review of the software design requirements and an exercising of the generated solution, within specified bounds, to demonstrate conformance to those requirements.

INTEGRATION – The process of combining H/S and S/W elements into specified configurations, verifying physical and logical compatibilities, verifying functionality and performance, and insuring that the configuration is ready for the next integration level. This effort is performed at specified (not necessarily the launch) site(s). This integration may utilize physical mock-ups, interface simulation, and access to processors for automation and maintainability verification.

VERIFICATION – The test/analysis program that proves system conformance to design, performance and suitability, e.g. safety, maintainability, reliability and environmental compatibility requirements. This effort is necessarily a distibuted operation that relies heavily on development, acceptance, certification, flight demonstration, preflight checkout testing augmented by analysis. This effort is normally a one time requirement and may expand the scope of normal test sequences for an early production article.

LAUNCH READINESS – The effort of verifying/servicing launch packages in preparation for boost to orbit and subsequent operations. This effort may be a multi-phase operation to:

- verify no shipping damage on delivery to launch site
- perform a limited checkout while in the orbiter bay.

XIV. CREW WORKSTATION

2.0 CREW WORKSTATION TRADE STUDY

The following trade studies analyze display type, color displays vs. monochrome, input controls, and caution and warning techniques for use in the NASA Space Station Crew Workstation. Figure 2.0 depicts the logic flow followed for each trade study. Initially, all NASA RFP requirements, NASA reference configurations, NASA standards, and independent technical studies are consolidated and analyzed to determine a viable set of options. The majority of this work was completed under Task Two, the options phase.

Using the NASA crew station RFP input requirements and program goals as listed in Table 2.0, a set of selection criteria is determined for each trade study. This selection criteria is the basis for which technology will be chosen. For each selection criteria a weighting factor is assigned that determines its relative importance to the Space Station program. Each option is also assigned a relative weighting factor with respect to the other options for a specific selection criteria. This relative weighting factor (0 - 10.0) defines, in a qualitative manner, the relative goodness of an option with respect to the other options for a specific selection criteria. The relative weighting is multiplied by the weighting factor and summed across all selection criteria for each option. The result is a figure of merit and indicates the most desirable, through the least desirable option, with respect to the Space Station program. In order to perpetuate an "intuitive feel" for this figure of merit it is divided by a perfect figure of merit, i.e., all relative weighting factors equal 10.0. The figure of merit is still a comparison of the options and also can be thought of as a percentage of the optimal technology.

FIGURE 2.0

TRADE STUDY LOGIC FLOW

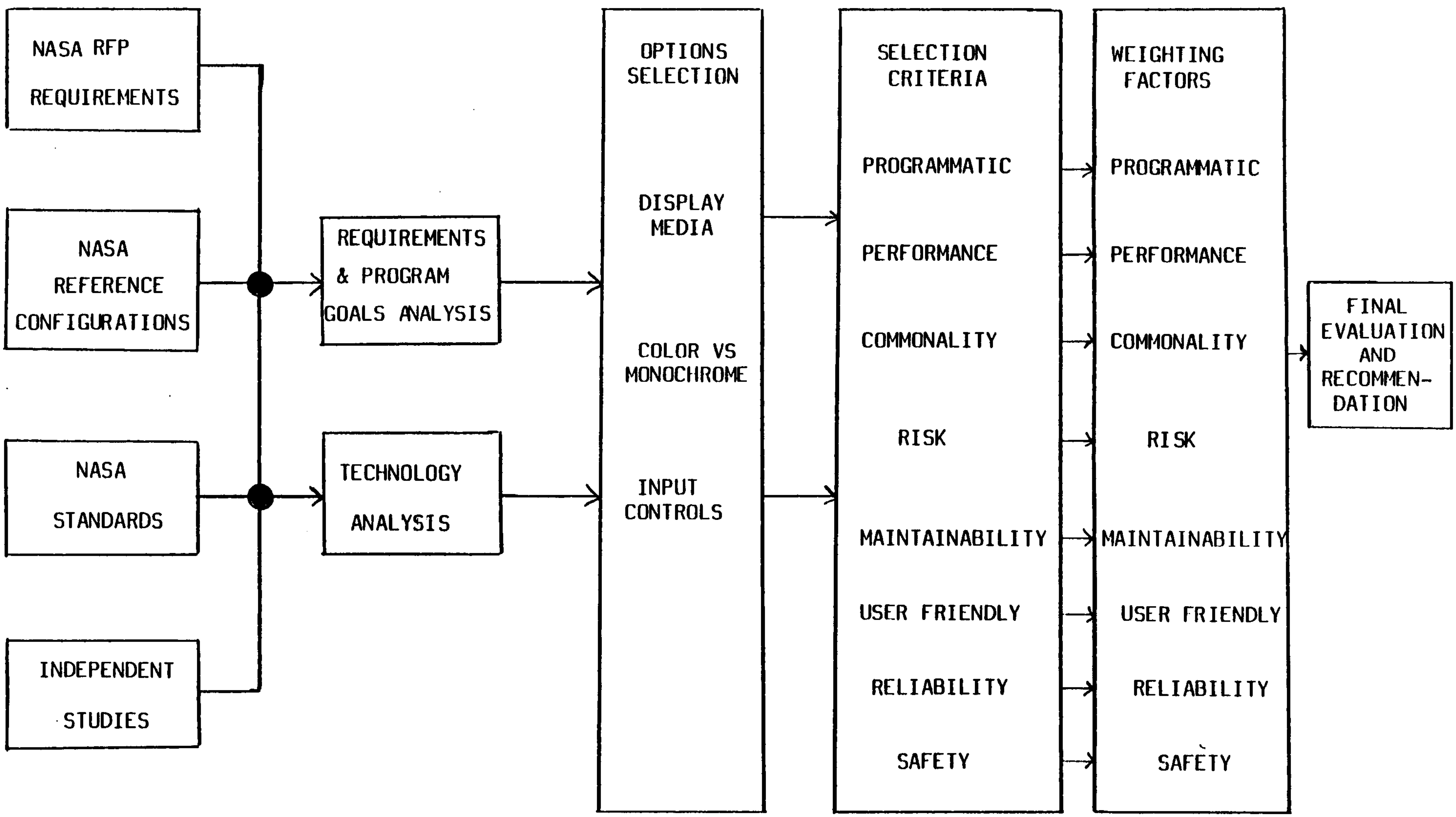


TABLE 2.0

CREW WORKSTATION DISPLAY & CONTROLS RFP REQUIREMENTS

MPAC RFP REQUIREMENTS

- C5 2.2.5.1c DMS General Rqmts, Opnl Intfcs

  The operational interface to the DMS shall be through the Multipurpose Application Consoles (MPAC) and the distributed computer processing system.

- C5 2.2.5.3.c DMS Dsgn and Perf Rqmts

  The fixed and portable MPAC shall be a common design functioning as a man/machine interface to the network operating system. The MPAC shall provide command and control, monitoring, operations and training capabilities. Furthermore, the MPAC shall provide:

  1. Visibility into all subsystems.
  2. Simultaneous viewing of displays.
  3. Crew override for subsystem operations.
  4. Annunciation for catastrophic failures, consistent with established caution and warning philosophy.

  The MPAC shall consist of the necessary displays, monitors, interactive controls and recording devices. The portable MPAC shall support both EVA and IVA operations.

TABLE 2.0

CREW WORKSTATION RFP REQUIREMENTS (continued)

- C5 2.2.5.3.c DMS Dsgn and Perf Rqmts

  The fixed and portable MPAC shall be a common design functioning as a man/machine interface to the network operating system. The portable MPAC shall support both EVA and IVA operations.

- C5 2.2.11.1.d EVA Functional Rqmts

  Portable workstations shall be designed for use with unprepared work sites.

- C3 3.2.d Sys Dsgn Featrs, Common, Rel and Maint

  A flight data file for crew use during IVA and EVA operation through portable work stations shall be provided. This system shall be complemented by IVA hardcopy devices as appropriate.

TABLE 2.0

CREW WORKSTATION RFP REQUIREMENTS (continued)

- C5 2.2.10.1a Hab/Man Sys, Sys Integ, Standardization

  Crew interfaces and associated equipment shall be standardized throughout the Space Station. Crew stations with multiple uses shall be used. Markings and labels shall utilize international standards/symbols throughout all modules.

- C5 2.2.10.1e Hab/Man Sys Sys Integ Dsps & Cntls

  Multifunction displays and controls shall be used. The following shall be designed to facilitate human productivity: character size, display brightness and contrast, auditory characteristics; control size, direction of motion, and types of controls; display format characteristics such as use of color, color controls, including tactile, visual, and auditory feedback requirements. Emergency operation of controls shall have a shape, texture, and location that is readily identifiable in the dark. The use of manually operated switches shall be minimized. Controls shall be protected against inadvertent operation.

TABLE 2.0

CREW WORKSTATION RFP REQUIREMENTS (continued)

- C5 2.2.10.2a Hab/Man Sys, Crew Statns, Work Statns

  A crew station shall be defined as any location in the Space Station where a dedicated task or activity is performed. A work station is a crew station which is exclusive of recreation, personal hygiene, food preparation, dining, housekeeping, and other off-duty activities. Accepted human factors engineering practices and criteria shall be used to design the human interface with the individual work stations. A thorough analysis of the requirements shall be done for each work station to determine the task, operator activities, level of automation, tools, equipment, etc. necessary to meet the requirements. Each work station shall meet the baseline safety requirements for the Space Station and will provide utility power. Work stations equipped to perform identical tasks (e.g., station housekeeping functions) shall utilize prime/backup logic with appropriate safeguards against dual functional path commanding, these work stations shall also satisfy the fail-safe criteria.

TABLE 2.0

CREW WORK STATIONS RFP REQUIREMENTS (continued)

- C5 2.2.10.2.b Crew stations/Window Work Stations

  All work stations associated with windows for operation and scientific research shall have provisions for the following items where dictated by the requirements analysis: display and keyboard.

- C3 3.1.3 Command, Control and Comm Support

  The information and data management services shall provide presentation services adequate to accommodate customer requirements. Access to the services shall be provided through standard network interface nodes and attached work stations.

TABLE 2.0

CREW WORK STATIONS RFP REQUIREMENTS (continued)

- 4.4.4.2.1.2 Multipurpose Applications Console (MPAC)

Fixed MPACs shall be used for routine operations. Portable MPACs shall handle operations away from the fixed units such as maintenance or operations where direct outside viewing through a window is desired. Both MPAC types will have multifunctional display screens and programmable controls.

Resident in the fixed MPAC will be the capability to print data and graphics from the display screen. The crew will have the capability to plot timed events data which will be selected from the MPAC. The operator will be able to choose between raw and processed data. In addition, a method for recording video images will be provided.

The design of the MPAC must take into account the zero-g environmental effects and astronaut positions. Granted that a local vertical is desired, a one-g rigidity in the design may not be desired. For example, the display screen may be positioned to any astronaut orientation.

TABLE 2.0

CREW WORK STATIONS RFP REQUIREMENTS (continued)

- 4.4.3.4 Video System

  The configuration, safety, and functional requirements of the Station call for control stations in each habitable module so that different crewmembers can perform their required tasks with minimal or no interruption to or from others. The system will be simple to operate since there will be a large number of users specialized in many different fields and special training for Space Station equipment is kept to a minimum.

  These requirements drive the design of the television system to a distributed control system where camera controls, video switching, and other system functions will be controlled from any workstation or monitoring location. This distributed control station concept will allow continuous operation even if parts of the Station become uninhabitable. These workstations will incorporate user-friendly input devices such as touch screen sensors, joysticks, and voice control inputs used in conjunction with color graphics generated menus and displays. The capability to move TV monitors from one location to another will be incorporated.

2.0.1 DISPLAYS SELECTION

2.0.1.1 Display Media Selection Criteria

The following lists each selection criteria that will be used in the displays media selection trade study. The selection criteria are divided into eight generic categories; programmatic considerations, performance parameters, risk assessment, maintainability, user-friendly, reliability, safety and operations support. These selection criteria are based on requirements and program goals set forth in the NASA RFP. Trade unique criteria were determined by independent technology research and defined in the Task Two Options Development Phase.

Programmatic Considerations

A. IOC Cost

B. Life Cycle Cost

C. Schedule Impact

Performance Parameters

A. Power

B. Volume

C. Contrast Ratio

D. Resolution

E. Driving Voltage

F. Ruggedization

G. Uniformity

H. Temperature Range

I. Color Capability

Risk Assessment

A. Technology State-of-the-Art

B. Producibility/Availability

Maintainability

A. Repairability

B. Replaceability

User-Friendly

A. Readability

B. Response Time

Reliability

A. Failure Rates

Safety

A. Failure Modes

B. Radiation Tolerance

Operations Support

A. Testability

Commonality

A. Application

2.0.1.2 Display Media Selection Weighting Factors

The following lists each weighting factor associated with each selection criteria used in the display media selection trade study. These weighting factors were determined by a panel of Sperry space station system personnel in conjunction with NASA RFP requirements emphasis.

Programmatic Weighting Factors

A. IOC Cost Weighting Factor = (0.8)

B. Life Cycle Cost Weighting Factor = (0.8)

C. Schedule Impact Weighting Factor = (0.3)

Performance Weighting Factors

A. Power Weighting Factor = (0.6)

B. Volume Weighting Factor = (0.6)

C. Contrast Ratio Weighting Factor = (0.4)

D. Resolution Weighting Factor = (0.1)

E. Driving Voltage Weighting Factor = (0.6)

F. Ruggedization Weighting Factor = (0.7)

G. Uniformity Weighting Factor = (0.1)

H. Temperature Range Weighting Factor = (0.7)

I. Color Capability Weighting Factor = (0.4)

Risk Weighting Factors

A. Technology State-of-the-Art Weighting Factor = (0.3)

B. Producibility/Availability Weighting Factor = (0.3)

Maintainability Weighting Factors

A. Repairability Weighting Factor = (0.5)

B. Replaceability Weighting Factor = (0.5)

User-Friendly Weighting Factors

A. Readability Weighting Factor = (0.4)

B. Response Time Weighting Factor = (0.4)

Reliability Weighting Factors

A. Failure Rates Weighting Factor = (0.5)

Safety Weighting Factors

A. Failure Modes Weighting Factor = (1.0)

Operations Support

A. Testability Weighting Factor = (0.5)

Commonality Weighting Factor

A. Application Weighting Factor = (0.4)

2.0.1.2 Display Media Trade Study

This trade study evaluates the use and desireability of the following display media for use in the Space Station Crew Workstations.

A. Cathode Ray Tube (CRT) Display

B. Plasma Flat Panel Display

C. Light Emitting Diode (LED) Flat Panel Display

D. Liquid Crystal Flat Panel Display (LCD)

E. Electroluminescent (EL) Flat Panel Display

Table 2.0.1.2 is the trade study results. Each display type and its associated selection criteria is given a qualitative rating within the display type set. Due to the rapid advancement in display technology and numerous displays which use each technology an overall assessment of excellent, good, fair and poor for each selection criteria is used.

From the trade study results, the order of display media preference is:

1. Liquid Crystal Flat Panel Display
2. Cathode Ray Tube
3. Electroluminescent Flat Panel Display
4. Plasma Flat Panel Display
5. Light Emitting Diode Flat Panel Display

Table 2.0.1.2 is the acutal trade study results. The following lists the order of preference, and the total dot product of the weighting factors and trade parameters, for the display media options.

1. Liquid Crystal Flat Panel Display - 81.8
2. Cathode Ray Tube - 78.4
3. Electroluminescent Flat Panel Display - 76.2
4. Plasma Flat Panel Display - 76.5
5. Light Emitting Diode Flat Panel Display - 65.4

A "figure of merit' is also calculated indicating the percentage of satisfying all selection criteria. These are as follows:

1. Liquid Crystal Flat Panel Display - 68.74
2. Cathode Ray Tube - 65.88
3. Electroluminescent Flat Panel Display - 64.03
4. Plasma Flat Panel Display - 64.29
5. Light Emitting Diode Flat Panel Display - 54.96

In general, the flat panel displays have an advantage over the CRT in the resource utilization department such as weight, volume, power and etc. The significant reason that the liquid crystal flat panel display is rated number one is that it also has color capability as does the CRT which is a close second. In reality either the CRT or liquid crystal flat panel display could be used on the NASA space station. The remaining flat panel technologies in all probability will not be suitable for the sophistication required for a space station display. Refer to the bar graph in Figure 2.0.1.2 for ease in viewing the trade study parameters in Table 2.0.1.2.

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

	PROGRAMMATIC			PERFORMANCE								
Options	IOC COST	LIFE CYCLE COST	SCHEDULE IMPACT	POWER	VOLUME	CONTRAST RATIO	RESOLUTION	DRIVING VOLTAGE	RUGGEDI-ZATION	UNIFORMITY	TEMPERA-TURE RANGE	COLOR CAPABILITY
CRT	Good R.W.=6.0 R.W.*W.F.= 4.8	Good R.W.=6.0 R.W.*W.F.= 4.8	Excellent R.W.=10.0 R.W.*W.F.= 3.0	Fair R.W.=3.0 R.W.*W.F.= 1.8	Poor R.W.=0.0 R.W.*W.F.= 0.0	Excellent R.W.=10.0 R.W.*W.F.= 4.0	Excellent R.W.=10.0 R.W.*W.F.= 1.0	Poor R.W.=0.0 R.W.*W.F.= 0.0	Good R.W.=6.0 R.W.*W.F.= 4.2	Excellent R.W.=10.0 R.W.*W.F.= 1.0	Good R.W.=6.0 R.W.*W.F.= 4.2	Excellent R.W.=10.0 R.W.*W.F.= 4.0
PLASMA FLAT PANEL	Good R.W.=6.0 R.W.*W.F.= 4.8	Good R.W.=6.0 R.W.*W.F.= 4.8	Good R.W.=6.0 R.W.*W.F.= 1.8	Good R.W.=6.0 R.W.*W.F.= 3.6	Good R.W.=6.0 R.W.*W.F.= 3.6	Good R.W.=6.0 R.W.*W.F.= 3.6	Good R.W.=6.0 R.W.*W.F.= 0.6	Fair R.W.=3.0 R.W.*W.F.= 1.8	Good R.W.=6.0 R.W.*W.F.= 4.2	Fair R.W.=3.0 R.W.*W.F.= 0.3	Good R.W.=6.0 R.W.*W.F.= 4.2	Good R.W.=6.0 R.W.*W.F.= 2.4
LIGHT EMITTING DIODE	Poor R.W.=0.0 R.W.*W.F.= 0.0	Poor R.W.=0.0 R.W.*W.F.= 0.0	Poor R.W.=0.0 R.W.*W.F.= 0.0	Poor R.W.=0.0 R.W.*W.F.= 0.0	Good R.W.=6.0 R.W.*W.F.= 3.6	Good R.W.=6.0 R.W.*W.F.= 2.4	Good R.W.=6.0 R.W.*W.F.= 0.6	Excellent R.W.=10.0 R.W.*W.F.= 6.0	Excellent R.W.=10.0 R.W.*W.F.= 7.0	Good R.W.=6.0 R.W.*W.F.= 0.6	Excellent R.W.=10.0 R.W.*W.F.= 7.0	Poor R.W.=0.0 R.W.*W.F.= 0.0
LIQUID CRYSTAL	Good R.W.=6.0 R.W.*W.F.= 4.8	Good R.W.=6.0 R.W.*W.F.= 4.8	Good R.W.=6.0 R.W.*W.F.= 1.8	Excellent R.W.=10.0 R.W.*W.F.= 3.0	Excellent R.W.=10.0 R.W.*W.F.= 6.0	Excellent R.W.=10.0 R.W.*W.F.= 4.0	Excellent R.W.=10.0 R.W.*W.F.= 1.0	Excellent R.W.=10.0 R.W.*W.F.= 1.0	Good R.W.=6.0 R.W.*W.F.= 4.2	Excellent R.W.=10.0 R.W.*W.F.= 1.0	Good R.W.=6.0 R.W.*W.F.= 4.2	Excellent R.W.=10.0 R.W.*W.F.= 4.0
ELECTROLU-MINESCENT	Good R.W.=6.0 R.W.*W.F.= 4.8	Good R.W.=6.0 R.W.*W.F.= 4.8	Good R.W.=6.0 R.W.*W.F.= 1.8	Good R.W.=6.0 R.W.*W.F.= 1.8	Good R.W.=6.0 R.W.*W.F.= 3.6	Good R.W.=6.0 R.W.*W.F.= 2.4	Good R.W.=6.0 R.W.*W.F.= 0.6	Fair R.W.=3.0 R.W.*W.F.= 1.8	Good R.W.=6.0 R.W.*W.F.= 4.2	Excellent R.W.=10.0 R.W.*W.F.= 1.0	Excellent R.W.=10.0 R.W.*W.F.= 7.0	Good R.W.=6.0 R.W.*W.F.= 2.4
Weighting factor	0.8	0.8	0.3	0.6	0.6	0.6	0.1	0.6	0.7	0.1	0.7	0.4

1 FOLDOUT FRAME

Table 2.0.1.2
Display Trade Study

2 FOLDOUT FRAME

ORIGINAL PAGE IS
OF POOR QUALITY

	RISK		MAINTAINABILITY		USER FRIENDLY		RELIABILITY	SAFETY		OPERATIONS SUPPORT	COMMON-ALITY	TOTALS (see Note)
Options	TECHNOLOGY SOA	PRODUCIBI-LITY/AVAIL-ABILITY	REPAIR-ABILITY	REPLACE-ABILITY	READ-ABILITY	RESPONSE TIME	FAILURE RATES	FAILURE MODES	RADIATION TOLERANCE	TEST-ABILITY	APPLI-CATION	FIGURE OF MERIT
CRT	Excellent R.W.=10.0 R.W.*W.F.= 6.0	Excellent R.W.=10.0 R.W.*W.F.= 6.0	Fair R.W.=3.0 R.W.*W.F.= 1.5	Good R.W.=6.0 R.W.*W.F.= 3.0	Good R.W.=6.0 R.W.*W.F.= 2.4	Excellent R.W.=10.0 R.W.*W.F.= 4.0	Fair R.W.=3.0 R.W.*W.F.= 1.5	Good R.W.=6.0 R.W.*W.F.= 6.0	Good R.W.=6.0 R.W.*W.F.= 4.2	Good R.W.=6.0 R.W.*W.F.= 3.0	Excellent R.W.=10.0 R.W.*W.F.= 8.0	Figure of Merit = 78.4 / 119 = 65.88
PLASMA FLAT PANEL	Good R.W.=6.0 R.W.*W.F.= 3.6	Good R.W.=6.0 R.W.*W.F.= 6.0	Poor R.W.=0.0 R.W.*W.F.= 0.0	Excellent R.W.=10.0 R.W.*W.F.= 5.0	Good R.W.=6.0 R.W.*W.F.= 2.4	Good R.W.=6.0 R.W.*W.F.= 2.4	Good R.W.=6.0 R.W.*W.F.= 3.0	Excellent R.W.=10.0 R.W.*W.F.= 10.0	Fair R.W.=3.0 R.W.*W.F.= 2.1	Fair R.W.=3.0 R.W.*W.F.= 1.5	Good R.W.=6.0 R.W.*W.F.= 4.8	Figure of Merit = 76.5 / 119 = 64.29
LIGHT EMITTING DIODE	Fair R.W.=3.0 R.W.*W.F.= 1.8	Good R.W.=6.0 R.W.*W.F.= 3.6	Poor R.W.=0.0 R.W.*W.F.= 0.0	Excellent R.W.=10.0 R.W.*W.F.= 5.0	Good R.W.=6.0 R.W.*W.F.= 2.4	Excellent R.W.=10.0 R.W.*W.F.= 4.0	Good R.W.=6.0 R.W.*W.F.= 3.0	Excellent R.W.=10.0 R.W.*W.F.= 10.0	Fair R.W.=3.0 R.W.*W.F.= 2.1	Fair R.W.=3.0 R.W.*W.F.= 1.5	Good R.W.=6.0 R.W.*W.F.= 4.8	Figure of Merit = 65.4 / 119 = 54.96
LIQUID CRYSTAL	Good R.W.=6.0 R.W.*W.F.= 3.6	Good R.W.=6.0 R.W.*W.F.= 3.6	Poor R.W.=0.0 R.W.*W.F.= 0.0	Excellent R.W.=10.0 R.W.*W.F.= 5.0	Excellent R.W.=10.0 R.W.*W.F.= 4.0	Good R.W.=6.0 R.W.*W.F.= 2.4	Excellent R.W.=10.0 R.W.*W.F.= 5.0	Excellent R.W.=10.0 R.W.*W.F.= 10.0	Fair R.W.=3.0 R.W.*W.F.= 2.1	Fair R.W.=3.0 R.W.*W.F.= 1.5	Good R.W.=6.0 R.W.*W.F.= 4.8	Figure of Merit = 81.8 / 119 = 68.74
ELECTROLU-MINESCENT	Good R.W.=6.0 R.W.*W.F.= 3.6	Good R.W.=6.0 R.W.*W.F.= 3.6	Poor R.W.=0.0 R.W.*W.F.= 0.0	Excellent R.W.=10.0 R.W.*W.F.= 5.0	Good R.W.=6.0 R.W.*W.F.= 2.4	Excellent R.W.=10.0 R.W.*W.F.= 4.0	Good R.W.=6.0 R.F.*W.F.= 3.0	Excellent R.W.=10.0 R.W.*W.F.= 10.0	Fair R.W.=3.0 R.W.*W.F.= 2.1	Fair R.W.=3.0 R.W.*W.F.= 1.5	Good R.W.=6.0 R.W.*W.F.= 4.8	Figure of Merit = 76.2 / 119 = 64.03
Weighting factor	0.6	0.6	0.5	0.5	0.4	0.4	0.5	1.0	0.7	0.5	0.8	

NOTE: Figure of merit = $\sum_{i=1}^{i=23} RW_i * WF_i \Big/ \sum_{i=1}^{i=23} RW_i(10) * WF_i$

Table 2.0.1.2 (cont.)
Display Trade Study

FOLDOUT FRAME

FOLDOUT FRAME

Figure 2.0.1.2
Display Trade Study

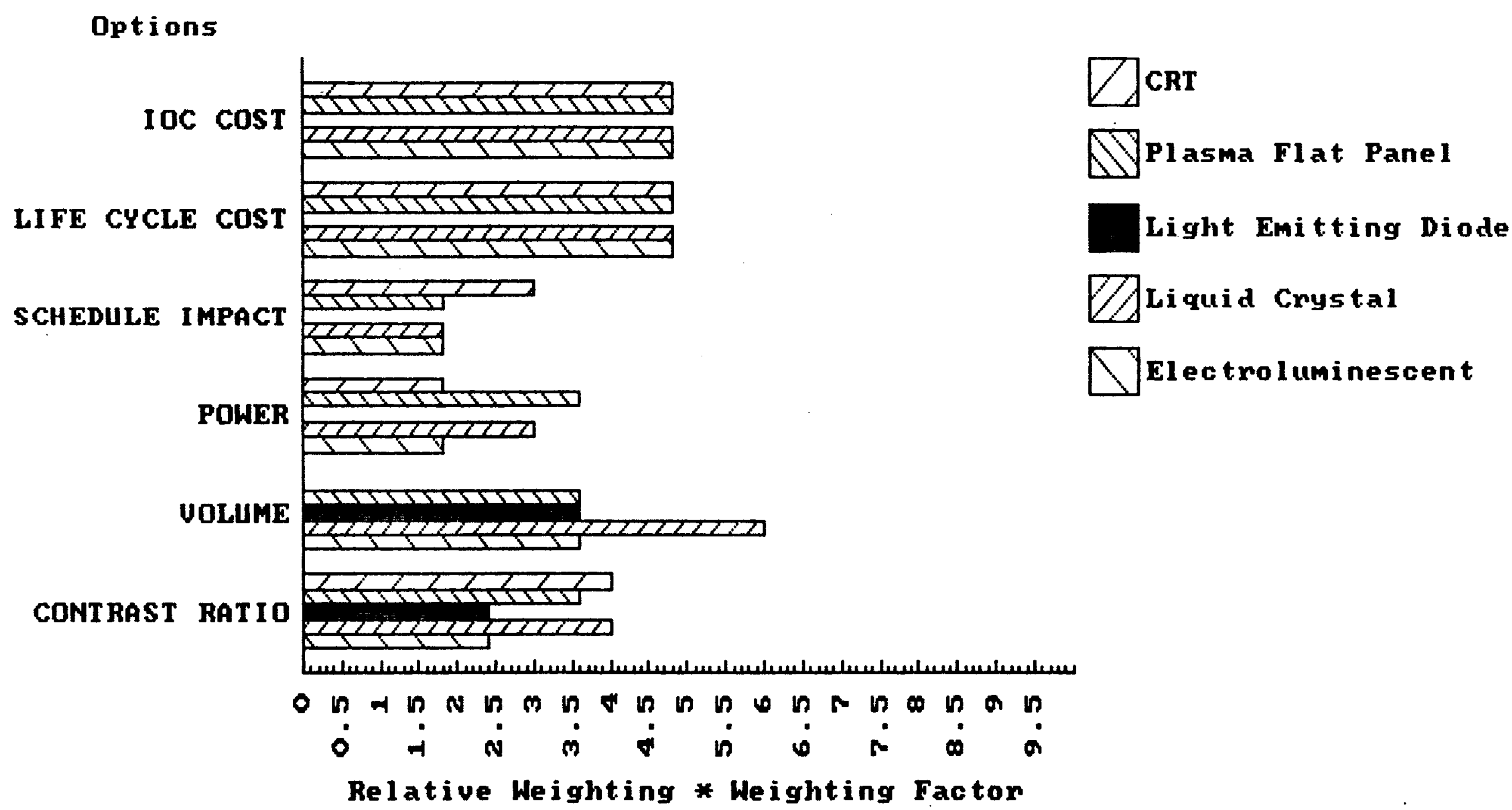


Figure 2.0.1.2 (cont.)
Display Trade Study

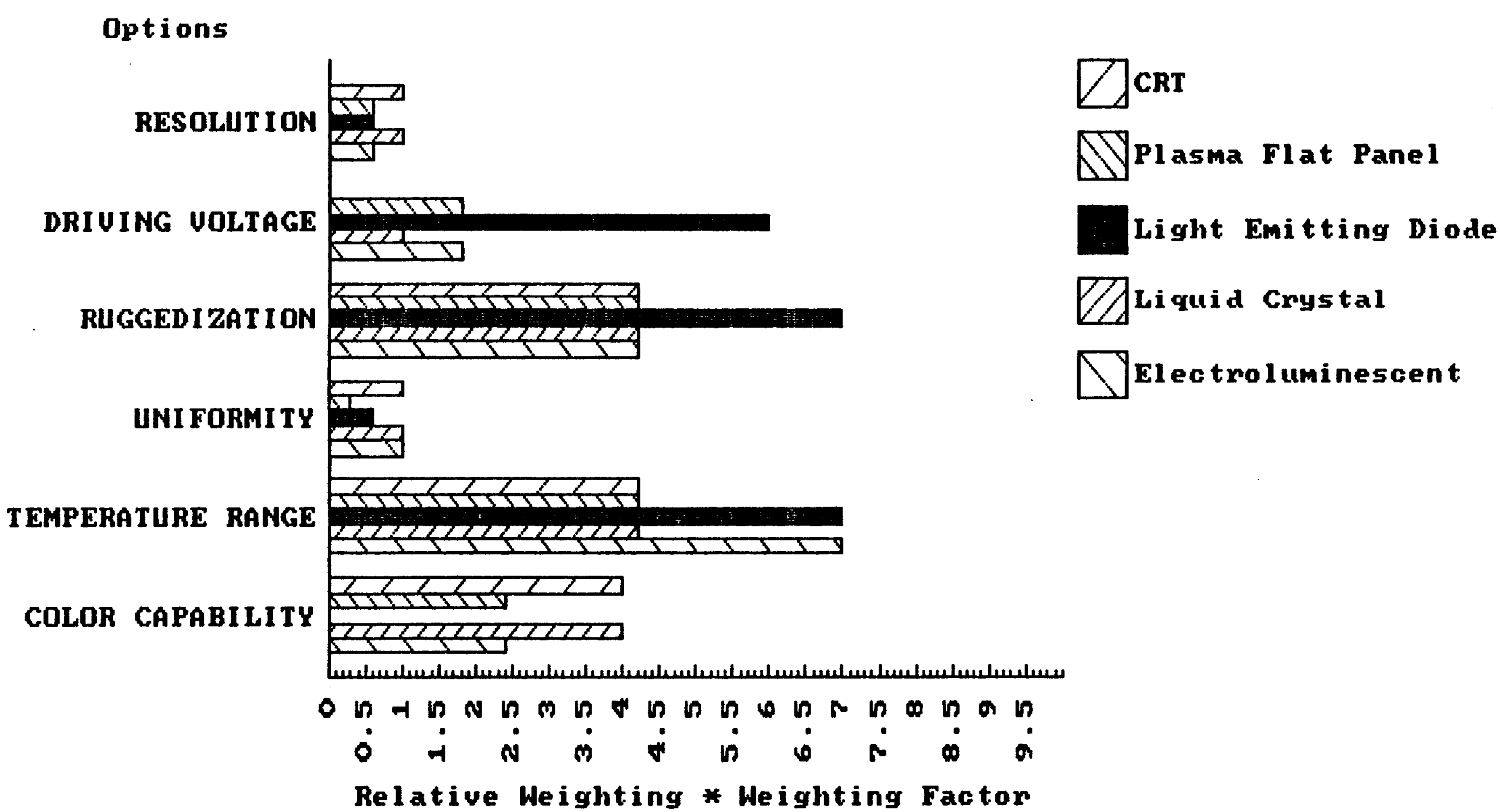


Figure 2.0.1.2 (cont.)
Display Trade Study

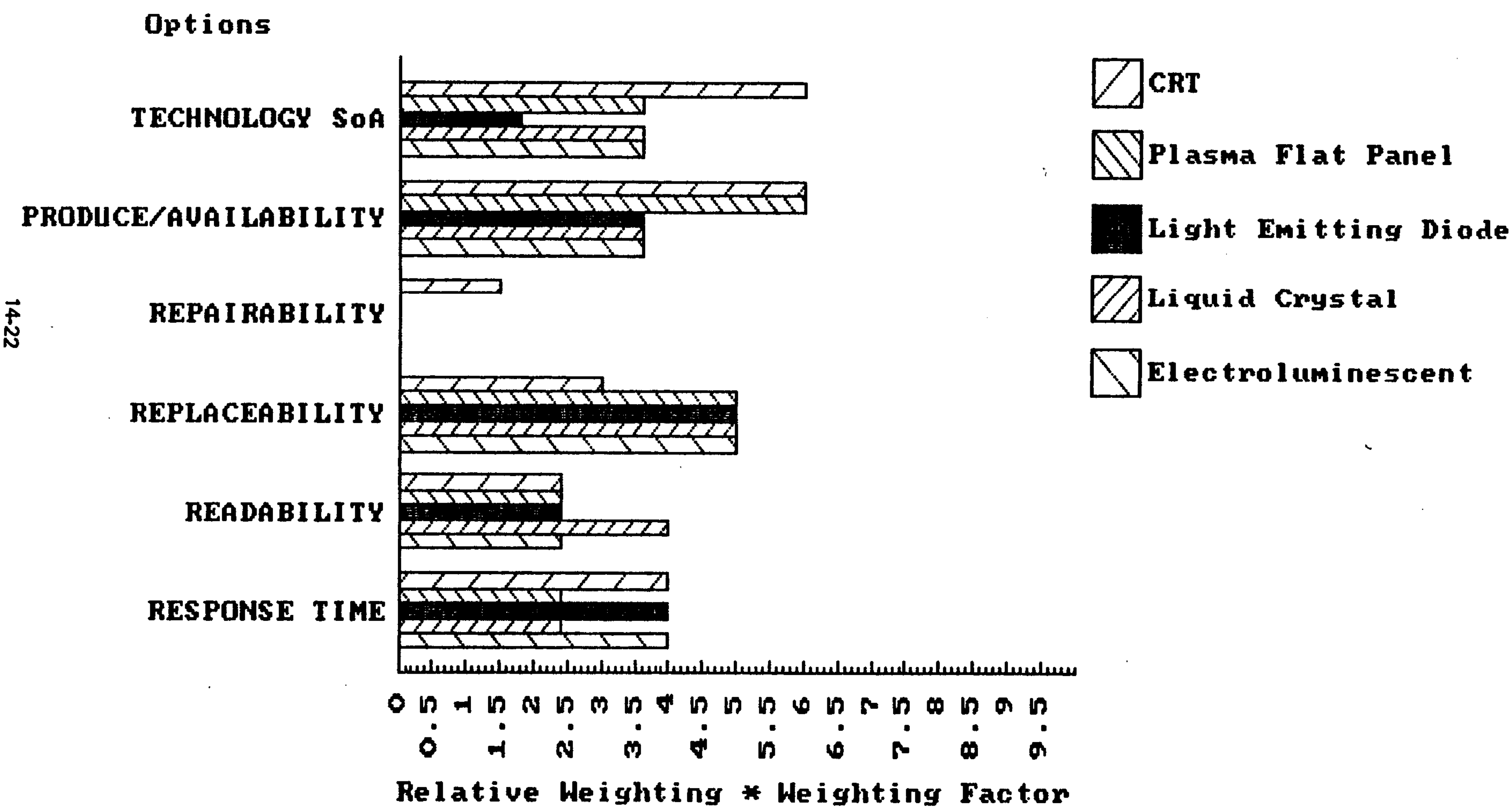
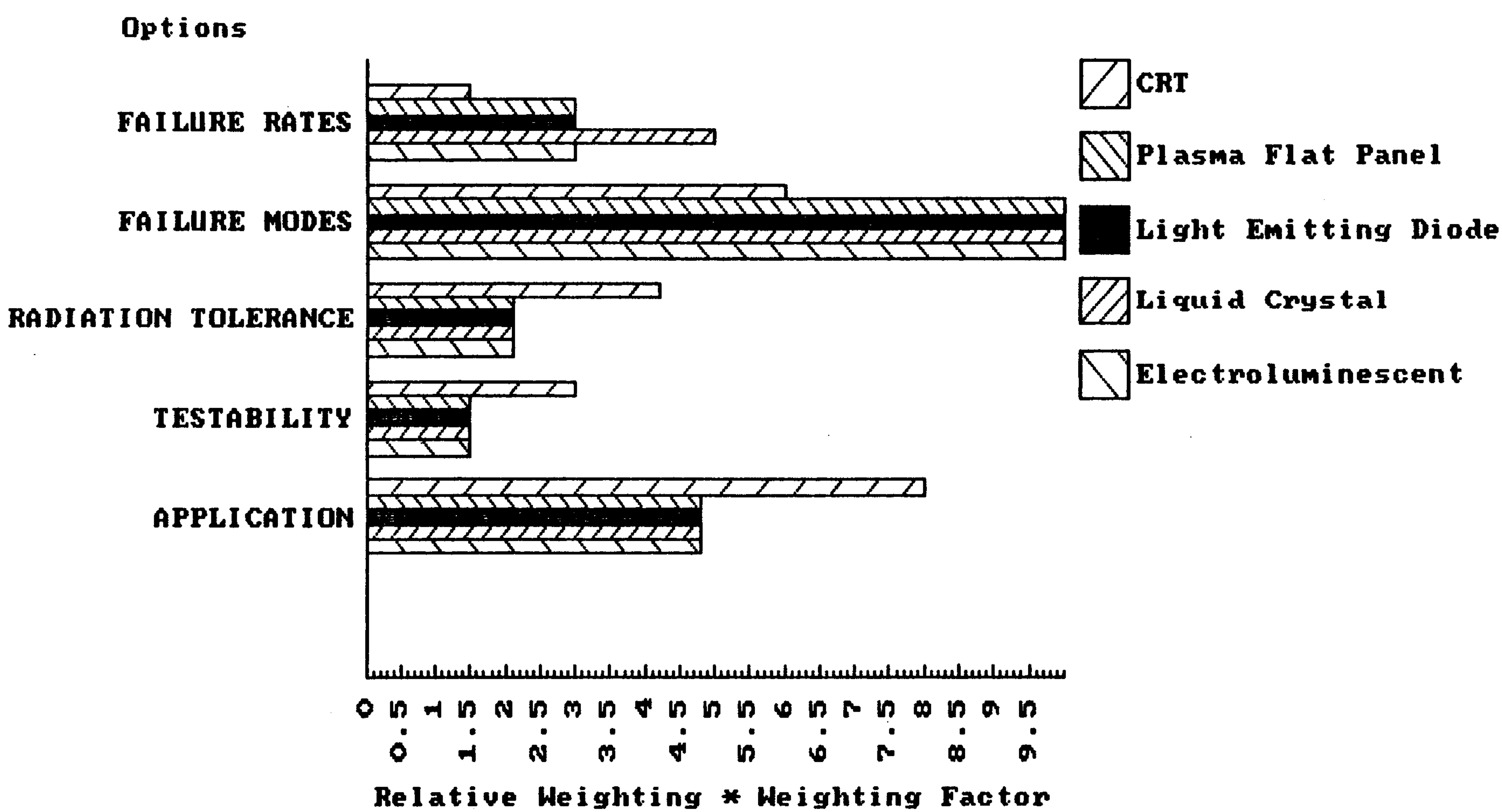


Figure 2.0.1.2 (cont.)
Display Trade Study



2.0.2 COLOR DISPLAY VS. MONOCHROME

2.0.2.1 Color Encoding vs. Monochrome Display Selection Criteria

The following lists each selection criteria that will be used in the color vs. monochrome display trade study. The selection criteria is divided into four generic categories; programmatic considerations, performance parameters, commonality considerations and risk assessment. These selection criteria are based on requirements and program goals set forth in the NASA RFP. Trade unique criteria were determined by independent technology research and defined in the Task Two Options Development Phase.

Programmatic Considerations

A. IOC Cost

B. Life Cycle Cost

C. Schedule Impact

Performance Parameters

A. Visual Data Assimilation

B. Information Content

C. Contrast Ratio

Commonality Considerations

A. Applications

Risk Assessment

A. Technology State-of-the-Art

B. Availability

2.0.2.2 Color Encoding vs. Monochrome Display Weighting Factors

The following lists each weighting factor associated with each selection criteria used in the color vs. monochrome display trade study. These weighting factors were determined by a panel of Sperry space station system personnel in conjunction with NASA RFP requirements emphasis.

Programmatic Weighting Factors

A. IOC Cost Weighting Factor = (0.8)

B. Life Cycle Cost Weighting Factor = (0.8)

C. Schedule Impact Weighting Factor = (0.3)

Performance Weighting Factors

A. Visual Data Assimilation Weighting Factor = (0.4)

B. Information Content Weighting Factor = (0.4)

C. Contrast Ratio Weighting Factor = (0.4)

Commonality Weighting Factors

A. Application Weighting Factor = (0.4)

Risk Criteria Weighting Factors

A. Technology SoA Weighting Factor = (0.3)

B. Availability Weighting Factor = (0.3)

2.0.2.3 Color Encoding vs. Monochrome Display Trade Study

This trade study evaluates the use of color for information display against the use of monochrome. Table 2.0.2.3 is the actual trade study results. Color displays have the advantage with a figure of merit of 84.63 against 72.68 for monochrome displays. From Figure 2.0.2.3 it is clear the main drivers for color displays is the visual data assimilation, information content, and application selection criteria.

Figure 2.0.2.3 is a bar graph representation of the data in Table 2.0.2.3. By visually scanning this figure it is immediately evident that the main drivers for color display information are the visual data assimilation, information content, and application selection criteria. Programmatic considerations tend to be slightly better for monochrome displays. This is not surprising since older, well established, technologies will always have lower cost, less schedule constraints and etc.

ORIGINAL PAGE IS
OF POOR QUALITY

Options	PROGRAMMATIC			PERFORMANCE			COMMONALITY	RISK		TOTALS
	IOC cost	Life Cycle Cost	Schedule Impact	Visual Data Assimilation	Information Content	Contrast Ratio	Application	Technology SoA	Availability	Figure of Merit: (see Note)
Color Display	IOC cost involves human factors research and standards involving color information presentation R.W.=8.0 R.W. * W.F. = 6.4	Color encoding research and development will be a continual process for each new display format R.W.=9.0 R.W. * W.F. = 7.2	Color information encoding and presentation could increase schedule R.W.=9.0 R.W. * W.F. = 2.7	Human assimilation of color coded information extremely high R.W.=10.0 R.W. * W.F. = 4.0	High display data content possible due to high data assimilation R.W.=10.0 R.W. * W.F. = 4.0	Software controllable contrast ratio through color combinations R.W.=10.0 R.W. * W.F. = 4.0	Color applicable to all display formats R.W.=10.0 R.W. * W.F. = 4.0	More research must be done on information enhancement using color R.W.=9.0 R.W. * W.F. = 2.7	Color CRT's are commercially available although full color flat panels are not R.W.=8.0 R.W. * W.F. = 2.4	Color displays are desireable and driven by the information content and data assimilation parameters Figure of merit = 37.4 / 41.0 = 84.63
Monochrome Display	Monochrome information display is well established and less complex than color R.W.=10.0 R.W. * W.F. = 8.0	New display formats will not require large information presentation development costs R.W.=10.0 R.W. * W.F. = 8.0	No schedule increase anticipated R.W.=10.0 R.W. * W.F. = 3.0	Assimilation of data improved only by information positioning R.W.=2.0 R.W. * W.F. = 0.8	Lower data assimilation implies lower display information requirements R.W.=2.0 R.W. * W.F. = 0.8	Fixed contrast ratio R.W.=5.0 R.W. * W.F. = 2.0	Monochrome has restricted applications R.W.=3.0 R.W. * W.F. = 1.2	Monochrome information enhancement well established R.W.=10.0 R.W. * W.F. = 3.0	Both monochrome CRT's and flat panels are commercially available R.W.=10.0 R.W. * W.F. = 3.0	Monochrome displays have many advantages but are not desireable from a crew performance viewpoint Figure of merit = 29.8 / 41.0 = 72.68
Weighting factor	0.8	0.8	0.3	0.4	0.4	0.4	0.4	0.3	0.3	

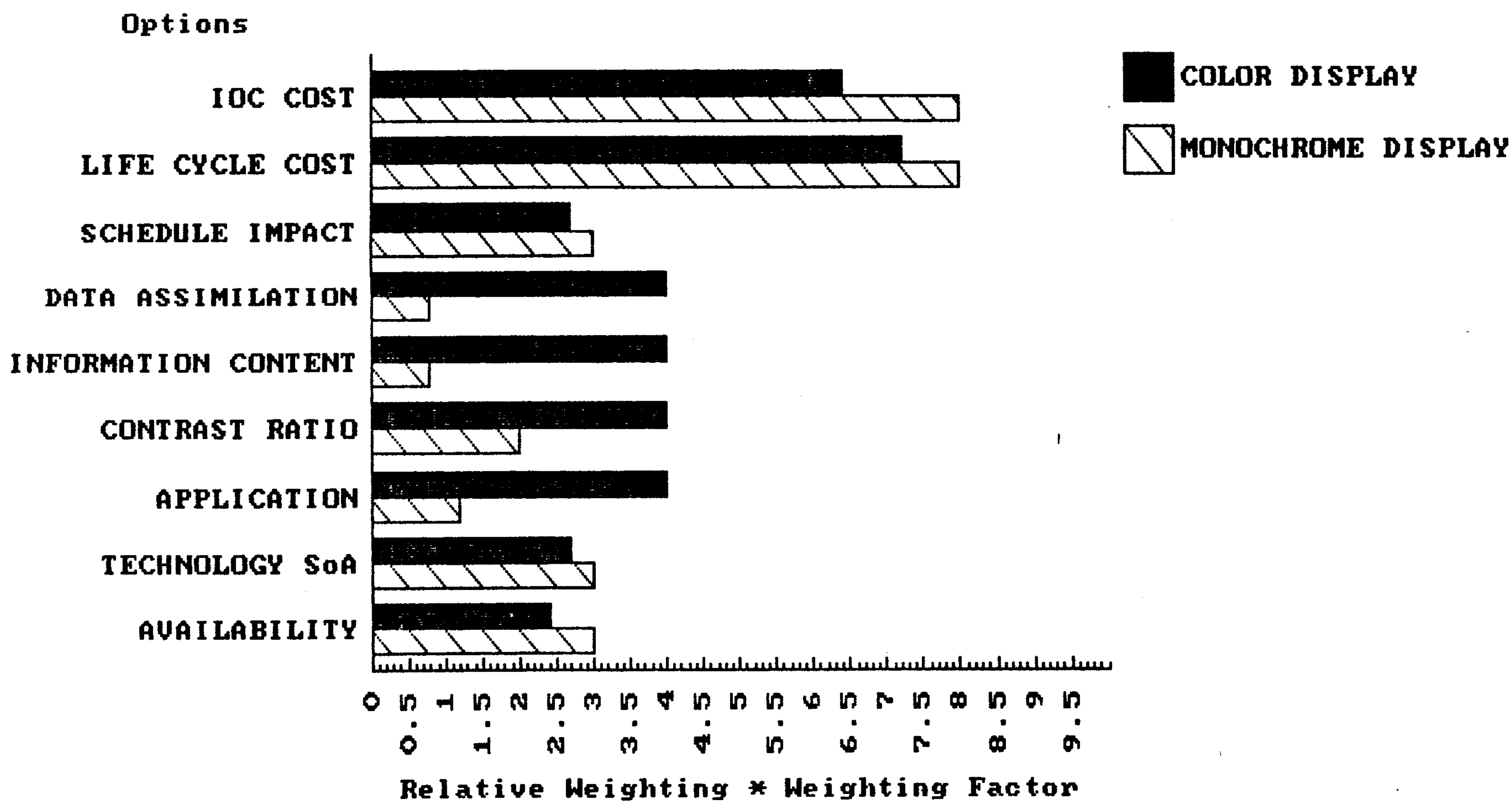
NOTE: Figure of merit = $\sum_{i=1}^{i=9} RW_i * WF_i \Big/ \sum_{i=1}^{i=9} RW_i(10) * WF_i$

Table 2.0.2.3
Color vs. Monochrome Display Trade Study

2 FOLDOUT FRAME

FOLDOUT FRAME

Figure 2.0.2.3
Color vs. Monochrome Display Trade Study



2.0.3 INPUT CONTROLS SELECTION

2.0.3.1 Input Controls Selection Criteria

The following lists each selection criteria that will be used in the input controls trade study. The selection criteria is divided into eight generic categories; programmatic considerations, performance parameters, commonality considerations, risk assessment, maintainability, user friendly reliability, and safety. These selection criteria are based on requirements and program goals set forth in the NASA RFP. Trade unique criteria were determined by independent technology research and defined in the Task Two Option Development Phase.

Programmatic Considerations

A. IOC Cost

B. Life Cycle Cost

C. Schedule Impact

Performance Parameters

A. Positioning

B. Speed

C. Portability

D. Ergonomics

E. Volume

F. Power

Commonality Considerations

A. Application

Risk Assessment

A. Technology State-of-the-Art

B. Producibility/Availability

Maintainability

A. Repairability

B. Replaceability

User Friendly

A. Response Time

Reliability

A. Failure Rates

Safety

A. Failure Modes

B. Radiation Tolerance

2.0.3.2 Input Controls Weighting Factor

The following lists each weighting factor associated with each selection criteria. These weighting factors were determined by a panel of Sperry space station personnel in conjunction with NASA RFP requirements emphasis.

Programmatic Weighting Factors

A. IOC Cost Weighting Factor = (0.8)

B. Life Cycle Cost Weighting Factor = (0.8)

C. Schedule Impact Weighting Factor = (0.3)

Performance Weighting Factors

A. Positioning Weighting Factor = (0.4)

B. Speed Weighting Factor = (0.4)

C. Portability Weighting Factor = (0.4)

D. Ergonomics Weighting Factor (0.4)

E. Volume Weighting Factor = (0.4)

F. Power Weighting Factor = (0.4)

Commonality Weighting Factors

A. Application Weighting Factor = (0.4)

Risk Weighting Factors

A. Technology S.A. Weighting Factor = (0.3)

B. Producibility/Availability Weighting Factor = (0.3)

Maintainability Weighting Factors

A. Repairability Weighting Factor = (0.5)

B. Replaceability Weighting Factor = (0.5)

User Friendly Weighting Factors

A. Response Time Weighting Factor = (0.4)

Reliability Weighting Factors

A. Failure Rates Weighting Factor = (0.5)

Safety Weighting Factors

A. Failure Modes Weighting Factor = (1.0)

B. Radiation Tolerance Weighting Factor = (0.7)

2.0.3.3 Input Controls Trade Study

This trade study evaluates the use and desirability of current input control types for use in the Space Station Crew Workstation. These input controls were selected and described in previous sections of this study, i.e., Task Two, options phase. The options selected were:

- Keyboard
- Touch Panel
- Joystick
- Light Pen
- Graphics Tablet
- Mouse
- Trackball
- Voice

Table 2.0.3.3 is the trade study results. The choice of a keyboard, touch panel, joystick, mouse, light pen or trackball or combination thereof would all be appropriate. The graphics tablet has deficiencies in the area of size, and voice in the area of technology State-of-the-Art. Either would not be desirable due to insufficiencies in these areas.

Table 2.0.3.3 is the actual trade study results. The following lists the order of preference, and the total dot product of the weighting factor vector and the trade parameter vector, for the input controls media options.

1. Keyboard - 96.80
2. Trackball - 96.40
3. Joystick - 94.50
4. Light Pen - 94.40
5. Touch Panel - 94.15
6. Mouse - 88.70
7. Graphics Tablet - 82.30
8. Voice - 72.57

A "figure of merit" is also calculated indicating the percentage of satisfying all selection criteria. These are as follows:

1. Keyboard - 93.81
2. Trackball - 93.59
3. Joystick - 91.75
4. Light Pen - 91.65
5. Touch Panel - 91.41
6. Mouse - 86.12
7. Graphics Tablet - 79.90
8. Voice - 72.57

The keyboard and trackball are the leading contenders for input control devices for the space station. In reality a keyboard and another input control device will probably be used. The trackball, joystic, light pen, touch panel and mouse are all candidates. Although the trackball is the preferred device, any of the above have potential for use on the space station.

For ease in interpreting the trade study, parameters in Table 2.0.3.3 refer to the bar graph in Figure 2.0.3.3.

ORIGINAL PAGE IS
OF POOR QUALITY

Options	PROGRAMMATIC			PERFORMANCE			
	IOC COST	LIFE CYCLE COST	SCHEDULE IMPACT	POSITIONING	SPEED	PORTABILITY	ERGONOMICS
KEYBOARD	Well established low cost technology R.W. = 9.5 R.W. * W.F. = 7.6	No dramatic technology change foreseen R.W. = 10.0 R.W. * W.F. = 8.0	No schedule impact due to well developed technology R.W. = 10.0 R.W. * W.F. = 3.0	Positioning with keyboard can be extremely accurate R.W. = 10.0 R.W. * W.F. = 4.0	Keyboard inputs and positioning is relatively slow R.W. = 8.0 R.W. * W.F. = 3.2	Somewhat cumbersome R.W. = 7.0 R.W. * W.F. = 2.8	Excellent ergonomic characteristics R.W. = 10.0 R.W. * W.F. = 4.0
TOUCH PANEL	Well established low cost technology R.W. = 10.0 R.W. * W.F. = 8.0	No dramatic technology change foreseen R.W. = 10.0 R.W. * W.F. = 8.0	No schedule impact due to well developed technology R.W. = 10.0 R.W. * W.F. = 3.0	Limited by finger width and screen size R.W. = 6.0 R.W. * W.F. = 2.4	Extremely fast R.W. = 10.0 R.W. * W.F. = 4.0	Attached to screen of display R.W. = 10.0 R.W. * W.F. = 4.0	Problems include smeared fingerprints and operator fatigue R.W. = 8.0 R.W. * W.F. = 3.2
JOYSTICK	Well established low cost technology R.W. = 10.0 R.W. * W.F. = 8.0	No dramatic technology change foreseen R.W. = 10.0 R.W. * W.F. = 8.0	No schedule impact due to well developed technology R.W. = 10.0 R.W. * W.F. = 3.0	High resolution R.W. = 10.0 R.W. * W.F. = 4.0	Rapid displacement R.W. = 9.0 R.W. * W.F. = 3.6	Small device R.W. = 8.0 R.W. * W.F. = 3.2	Excellent ergonomic characteristics R.W. = 10.0 R.W. * W.F. = 4.0
LIGHT PEN	Well established low cost technology R.W. = 10.0 R.W. * W.F. = 8.0	No dramatic technology change foreseen R.W. = 10.0 R.W. * W.F. = 8.0	No schedule impact due to well developed technology R.W. = 10.0 R.W. * W.F. = 3.0	Very high resolution - pen width R.W. = 10.0 R.W. * W.F. = 4.0	Push button to activate R.W. = 8.0 R.W. * W.F. = 3.2	Pencil size device R.W. = 9.0 R.W. * W.F. = 3.6	Can cause operator fatigue R.W. = 8.0 R.W. * W.F. = 3.2
GRAPHICS TABLET	Well established low cost technology R.W. = 10.0 R.W. * W.F. = 8.0	No dramatic technology change foreseen R.W. = 10.0 R.W. * W.F. = 8.0	No schedule impact due to well developed technology R.W. = 10.0 R.W. * W.F. = 3.0	High resolution may exceed human manipulative ability R.W. = 10.0 R.W. * W.F. = 4.0	Rapid displacement R.W. = 9.0 R.W. * W.F. = 3.6	Cumbersome R.W. = 1.0 R.W. * W.F. = 0.4	Consumes large areas of space R.W. = 2.0 R.W. * W.F. = 0.8
MOUSE	Well established low cost technology R.W. = 10.0 R.W. * W.F. = 8.0	No dramatic technology change foreseen R.W. = 10.0 R.W. * W.F. = 8.0	No schedule impact due to well developed technology R.W. = 10.0 R.W. * W.F. = 3.0	Some slippage error R.W. = 5.0 R.W. * W.F. = 2.0	Rapid displacement R.W. = 9.0 R.W. * W.F. = 3.6	Small device but need counter space to operate R.W. = 2.0 R.W. * W.F. = 0.8	Questionable operation in zero-G environment R.W. = 2.0 R.W. * W.F. = 0.8
TRACKBALL	Well established low cost technology R.W. = 10.0 R.W. * W.F. = 8.0	No dramatic technology change foreseen R.W. = 10.0 R.W. * W.F. = 8.0	No schedule impact due to well developed technology R.W. = 10.0 R.W. * W.F. = 3.0	Small cursor increments R.W. = 9.5 R.W. * W.F. = 3.8	Rapid displacement R.W. = 9.0 R.W. * W.F. = 3.6	Small device R.W. = 8.0 R.W. * W.F. = 3.2	Excellent ergonomic characteristics R.W. = 10.0 R.W. * W.F. = 4.0
VOICE	High cost - technology needs improvement R.W. = 6.0 R.W. * W.F. = 4.8	High technology cost associated with voice improvements R.W. = 6.0 R.W. * W.F. = 4.8	New technology break-throughs needed for voice R.W. = 7.0 R.W. * W.F. = 2.1	Very high resolution R.W. = 10.0 R.W. * W.F. = 4.0	Extremely fast R.W. = 10.0 R.W. * W.F. = 4.0	Software implemented and essential non-portable R.W. = 2.0 R.W. * W.F. = 0.8	Noise, voice deflections, and patterns areas of concern R.W. = 7.0 R.W. * W.F. = 2.8
Weighting factor	0.8	0.8	0.3	0.4	0.4	0.4	0.4

1 FOLDOUT FRAME

2 FOLDOUT FRAME

Table 2.0.3.3
Input Controls Trade Study

ORIGINAL PAGE IS
OF POOR QUALITY

	PERFORMANCE (cont.)		COMMONALITY	RISK		MAINTAINABILITY	
Options	VOLUME	POWER	APPLICATION	TECHNOLOGY SOA	PRODUCIBLILITY/ AVAILABILITY	REPAIRABILITY	REPLACEABILITY
KEYBOARD	Tend to consume space R.W. = 8.0 R.W. * W.F. = 4.8	Low voltage device R.W. = 9.0 R.W. * W.F. = 5.4	Can be used for all applications R.W. = 10.0 R.W. * W.F. = 8.0	Well developed technology R.W. = 10.0 R.W. * W.F. = 6.0	Commercially available R.W. = 10.0 R.W. * W.F. = 6.0	Repair complex R.W. = 6.0 R.W. * W.F. = 3.0	Plug-in unit - Replaceable ORU R.W. = 10.0 R.W. * W.F. = 5.0
TOUCH PANEL	Occupies virtually no space R.W. = 10.0 R.W. * W.F. = 4.0	Requires light emitters, receptors, and processing cicuitry R.W. = 8.0 R.W. * W.F. = 4.8	Limited to activating CMD'S from display R.W. = 8.0 R.W. * W.F. = 6.4	Well developed technology R.W. = 10.0 R.W. * W.F. = 6.0	Commercially available R.W. = 10.0 R.W. * W.F. = 6.0	Repair complex R.W. = 5.0 R.W. * W.F. = 5.5	Bezel disassembly R.W. = 8.5 R.W. * W.F. = 4.25
JOYSTICK	Small device R.W. = 9.0 R.W. * W.F. = 3.6	Extremely low voltage R.W. = 10.0 R.W. * W.F. = 6.0	Limited to cursor movement R.W. = 7.0 R.W. * W.F. = 5.6	Well developed technology R.W. = 10.0 R.W. * W.F. = 6.0	Commercially available R.W. = 10.0 R.W. * W.F. = 6.0	Repair complex R.W. = 5.0 R.W. * W.F. = 2.5	Plug-in unit - Replaceable ORU R.W. = 10.0 R.W. * W.F. = 5.0
LIGHT PEN	Very small device R.W. = 9.5 R.W. * W.F. = 5.7	Requires processing circuitry R.W. = 8.0 R.W. * W.F. = 4.8	Limited to activating CMD's from display R.W. = 8.0 R.W. * W.F. = 6.4	Well developed technology R.W. = 10.0 R.W. * W.F. = 6.0	Commercially available R.W. = 10.0 R.W. * W.F. = 6.0	Repair complex R.W. = 5.0 R.W. * W.F. = 2.5	Plug-in unit - Replaceable ORU R.W. = 10.0 R.W. * W.F. = 5.0
GRAPHICS TABLET	Occupies large desk top areas R.W. = 2.0 R.W. * W.F. = 1.2	Requires processing circuitry R.W. = 8.0 R.W. * W.F. = 4.8	Limited use R.W. = 5.0 R.W. * W.F. = 4.0	Well developed technology R.W. = 10.0 R.W. * W.F. = 6.0	Commercially available R.W. = 10.0 R.W. * W.F. = 6.0	Repair complex R.W. = 5.0 R.W. * W.F. = 2.5	Plug-in unit - Replaceable ORU R.W. = 10.0 R.W. * W.F. = 5.0
MOUSE	Small device R.W. = 9.0 R.W. * W.F. = 5.4	Extremely low voltage R.W. = 10.0 R.W. * W.F. = 6.0	Limited to cursor movement R.W. = 7.0 R.W. * W.F. = 5.6	Well developed technology R.W. = 10.0 R.W. * W.F. = 6.0	Commercially available R.W. = 10.0 R.W. * W.F. = 6.0	Repair complex R.W. = 5.0 R.W. * W.F. = 2.5	Plug-in unit - Replaceable ORU R.W. = 10.0 R.W. * W.F. = 5.0
TRACKBALL	Small device R.W. = 9.5 R.W. * W.F. = 5.7	Extremely low voltage R.W. = 10.0 R.W. * W.F. = 6.0	Limited to cursor movement R.W. = 7.0 R.W. * W.F. = 5.6	Well developed technology R.W. = 10.0 R.W. * W.F. = 6.0	Commercially available R.W. = 10.0 R.W. * W.F. = 6.0	Repair complex R.W. = 5.0 R.W. * W.F. = 2.5	Plug-in unit - Replaceable ORU R.W. = 10.0 R.W. * W.F. = 5.0
VOICE	Associated hardware consumes space R.W. = 6.0 R.W. * W.F. = 3.6	Requires software and processor R.W. = 2.0 R.W. * W.F. = 1.2	With correct technology can be used for all applications R.W. = 9.0 R.W. * W.F. = 7.2	Technology needs vast improvement R.W. = 6.0 R.W. * W.F. = 3.6	Produceability no problem once technology developed R.W. = 9.5 R.W. * W.F. = 5.7	Complex processor repair R.W. = 5.0 R.W. * W.F. = 2.5	Involves processor changeout R.W. = 9.0 R.W. * W.F. = 4.5
Weighting factor	0.6	0.6	0.8	0.6	0.6	0.5	0.5

FOLDOUT FRAME

Table 2.0.3.3 (cont.)
Input Controls Trade Study

FOLDOUT FRAME

	USER FRIENDLY	RELIABILITY	SAFETY		TOTAL
Options	RESPONSE TIME	FAILURE RATES	FAILURE MODES	RADIATION TOLERANCE	FIGURE OF MERIT (see Note)
KEYBOARD	No response time problems R.W. = 10.0 R.W. * W.F. = 4.0	Low R.W. = 10.0 R.W. * W.F. = 5.0	Fail safe R.W. = 10.0 R.W. * W.F. = 10.0	None R.W. = 10.0 R.W. * W.F. = 7.0	Figure of merit= 96.80 / 103.00 = 93.81
TOUCH PANEL	No response time problems R.W. = 10.0 R.W. * W.F. = 4.0	Low R.W. = 10.0 R.W. * W.F. = 5.0	Fail safe R.W. = 10.0 R.W. * W.F. = 10.0	Some technologies are radiation sensitive R.W. = 8.0 R.W. * W.F. = 5.6	Figure of merit= 94.15 / 103.00 = 91.41
JOYSTICK	No response time problems R.W. = 10.0 R.W. * W.F. = 4.0	Low R.W. = 10.0 R.W. * W.F. = 5.0	Fail safe R.W. = 10.0 R.W. * W.F. = 10.0	None R.W. = 10.0 R.W. * W.F. = 7.0	Figure of merit= 94.50 / 103.00 = 91.75
LIGHT PEN	No response time problems R.W. = 10.0 R.W. * W.F. = 4.0	Medium R.W. = 8.0 R.W. * W.F. = 4.0	Fail safe R.W. = 10.0 R.W. * W.F. = 10.0	None R.W. = 10.0 R.W. * W.F. = 7.0	Figure of merit= 94.40 / 103.00 = 91.65
GRAPHICS TABLET	No response time problems R.W. = 10.0 R.W. * W.F. = 4.0	Medium R.W. = 8.0 R.W. * W.F. = 4.0	Fail safe R.W. = 10.0 R.W. * W.F. = 10.0	None R.W. = 10.0 R.W. * W.F. = 7.0	Figure of merit= 82.30 / 103.00 = 79.90
MOUSE	No response time problems R.W. = 10.0 R.W. * W.F. = 4.0	Low R.W. = 10.0 R.W. * W.F. = 5.0	Fail safe R.W. = 10.0 R.W. * W.F. = 10.0	None R.W. = 10.0 R.W. * W.F. = 7.0	Figure of merit= 88.70 / 103.00 = 86.12
TRACKBALL	No response time problems R.W. = 10.0 R.W. * W.F. = 4.0	Low R.W. = 10.0 R.W. * W.F. = 5.0	Fail safe R.W. = 10.0 R.W. * W.F. = 10.0	None R.W. = 10.0 R.W. * W.F. = 7.0	Figure of merit= 96.40 / 103.00 = 93.59
VOICE	Function of vocabulary and sophistication R.W. = 8.0 R.W. * W.F. = 3.2	Medium R.W. = 8.0 R.W. * W.F. = 4.0	Fail safe R.W. = 10.0 R.W. * W.F. = 10.0	Hardware must be radiation hardened R.W. = 8.5 R.W. * W.F. = 5.95	Figure of merit= 77.75 / 103.00 = 72.57
Weighting factor	0.4	0.5	1.0	0.7	

NOTE: Figure of merit= $\sum_{i=1}^{i=18} RW_i * WF_i \Big/ \sum_{i=1}^{i=18} RW_i(10) * WF_i$

Table 2.0.3.3 (cont.)
Input Controls Trade Study

1 FOLDOUT FRAME

2 FOLDOUT FRAME

Figure 2.0.3.3
Input Controls Trade Study

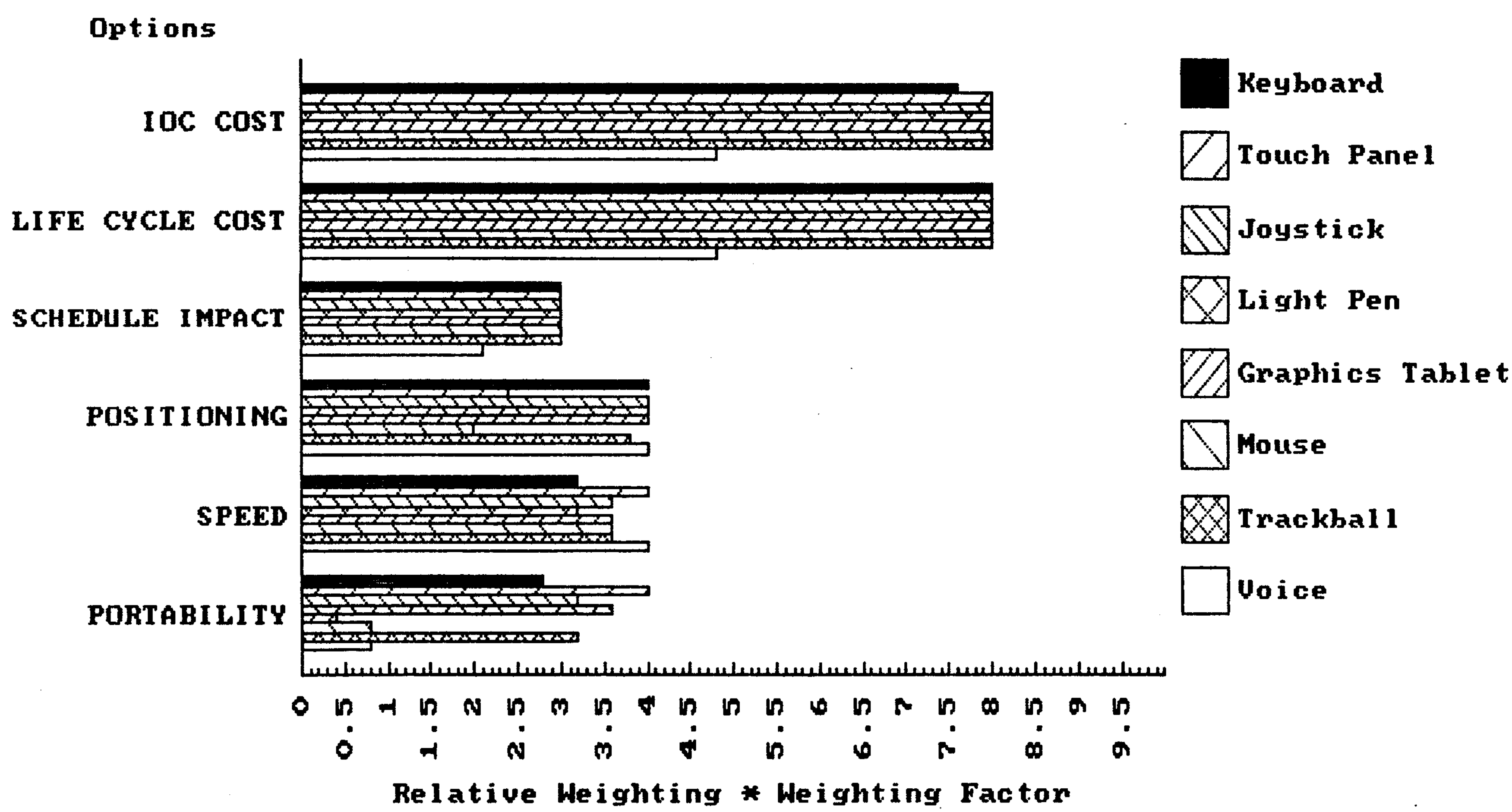


Figure 2.0.3.3 (cont.)
Input Controls Trade Study

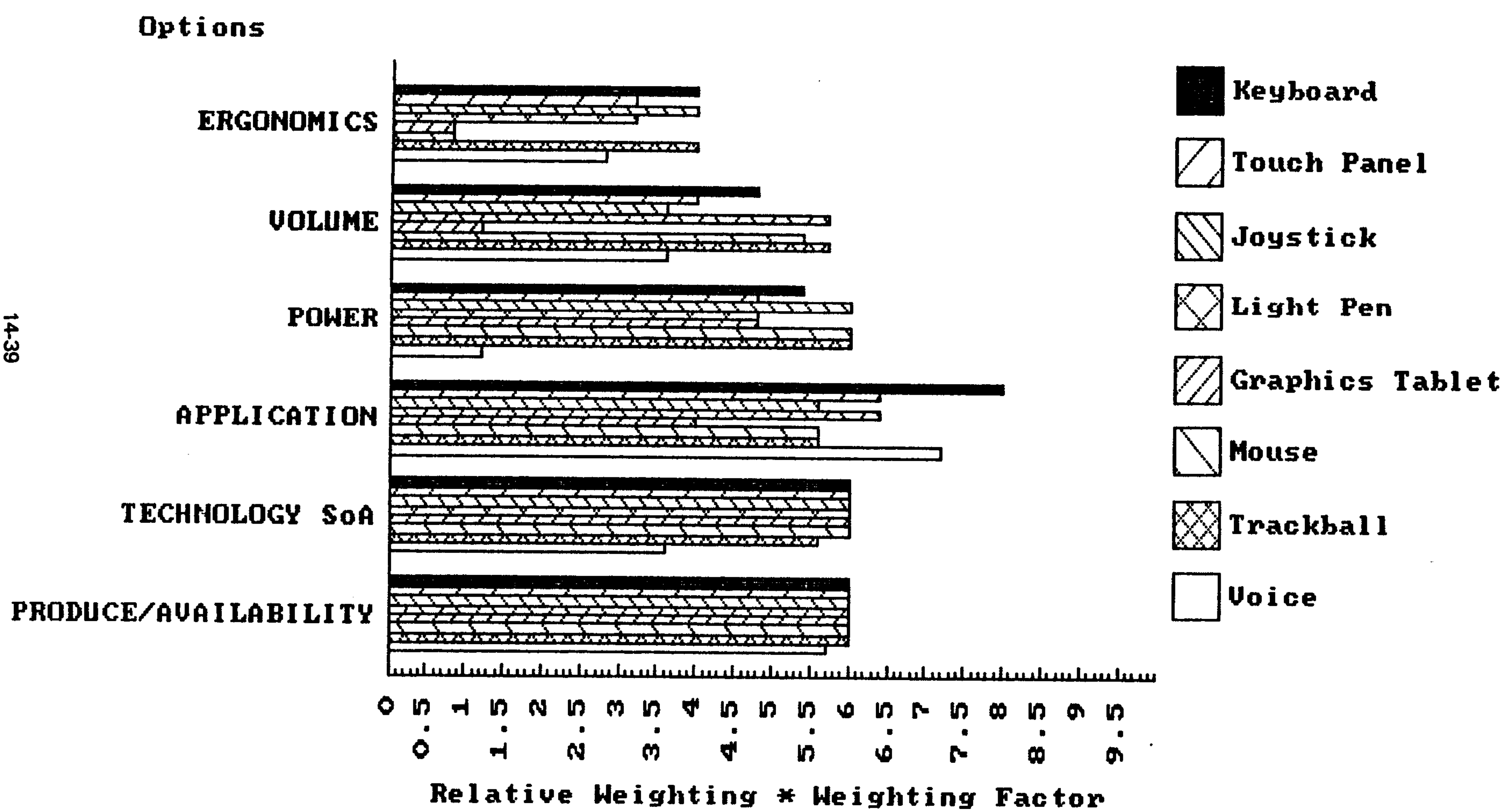
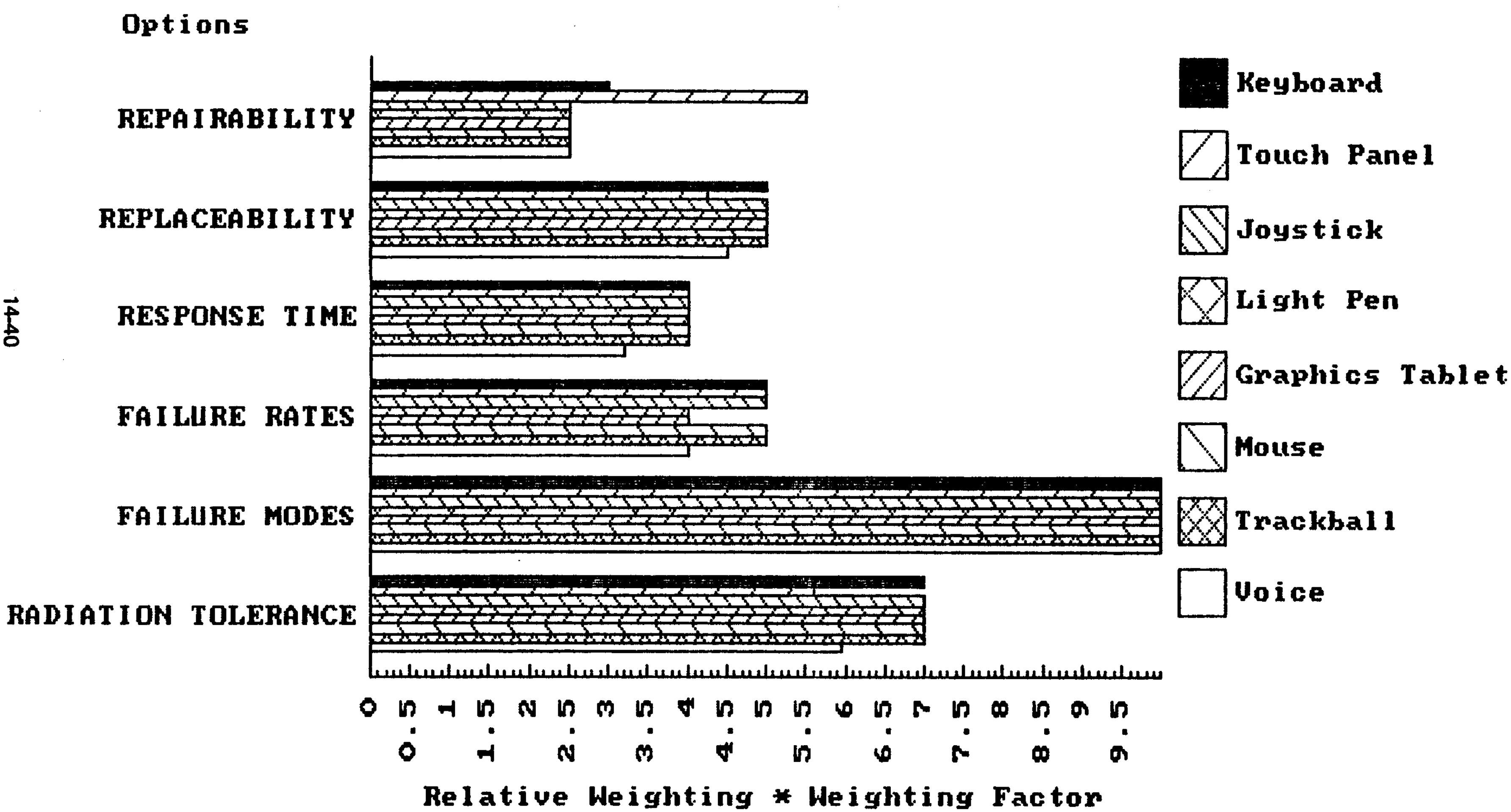


Figure 2.0.3.3 (cont.)
Input Controls Trade Study



2.0.4 CAUTION AND WARNING SYSTEM SELECTION

2.0.4.1 Caution and Warning Selection Criteria

The following lists each selection criteria that will be used in the caution and warning trade study. The selection criteria is divided into six generic categories; programmatic considerations, performance parameters, risk assessment, growth and evolution, safety, and user friendly. These selection criteria are based on requirements and program goals set forth in the NASA RFP. Trade unique criteria were determined by independent technology research and defined in the Task Two Options Development Phase.

Programmatic Considerations

A. IOC Cost

B. Life Cycle Cost

C. Schedule Impact

Performance Parameters

A. Power

B. Volume

C. Alarm Recognition

D. Controllability

E. Alerts

F. Ergonomics

Risk Assessment

A. Technology State-of-the-Art

B. Availability

Growth and Evolution

A. Growth Capability

Safety

A. Failure Modes

User Friendly

A. Crew Performance

2.0.4.2 Caution and Warning Weighting Criteria

The following lists each weighting factor associated with each selection criteria used in the caution and warning trade study.

Programmatic Weighting Factors

A. IOC Cost Weighting Factor = (0.8)

B. Life Cycle Cost Weighting Factor = (0.8)

C. Schedule Impact Weighting Factor = (0.3)

Performance Weighting Factors

A. Power Weighting Factor = (0.6)

B. Volume Weighting Factor = (0.6)

C. Alarm Recognition Weighting Factor = (1.0)

D. Controllability Weighting Factor = (0.7)

E. Alerts Weighting Factor = (0.7)

F. Ergonomics Weighting Factor = (0.4)

Risk Assessment

A. Technology State-of-the-Art Weighting Factor = (0.3)

B. Availability Weighting Factor = (0.3)

Growth and Evolution

A. Growth Capability Weighting Factor = (0.6)

Safety

A. Failure Modes Weighting Factor = (1.0)

User Friendly

A. Crew Performance Weighting Factor = (0.4)

2.0.4.3 Caution and Warning Trade Study

This trade study evaluates the use and desirability of a distributed or integrated caution and warning system for use on the NASA Space Station. The options and characteristics were developed in the Task Two Options Development Phase.

It is quite clear that an integrated caution and warning system is the overall preferred system with a figure of merit of 94.59. The distributed caution and warning system obtained a figure of merit of 65.06 or 29.53 points below the integrated caution and warning system. This result is a reflection of current problems encountered in current distributed avionic caution and warning systems.

Table 2.0.4.3 is an overall bar chart graph of the trade study results. It is easily seen that the main drivers in choosing an integrated system are: alarm recognition, controllability and failure modes. These areas are also areas of concern in todays avionics caution and warning systems.

In today's distributed caution and warning systems alarm recognition is a problem due to the proliferation of alerts inhibiting the ability to correlate the alarm to a specific problem area. Distributed systems also prevent the categorizing and prioritizing alerts; an extremely important task during periods of high workload. During this period of high workload non-critical alerts may not be inhibited or controllable in a distributed system, leading to a saturating of crew members processing capabilities. This may lead to dangerous failure modes by superfluous or misleading error alerts or alarms.

ORIGINAL PAGE IS
OF POOR QUALITY

Options	PROGRAMMATIC			PERFORMANCE				
	IOC COST	LIFE CYCLE COST	SCHEDULE IMPACT	POWER	VOLUME	ALARM RECOGNITION	CONTROLLABILITY	ALERTS
DISTRIBUTED CAUTION AND WARNING SYSTEM	Cost will be moderately high for distributed system due to hardware and processing redundancy. R.W. = 10.0 R.W. * W.F. = 8.0	Cost will be high over the life cycle of the space station due to proliferation of hardware, power and space problem areas. R.W. = 8.0 R.W. * W.F. = 6.4	Distributed advisory, caution and warning systems are not complex and should not create schedule constraints. R.W. = 10.0 R.W. * W.F. = 3.0	Power must be supplied to all distributed systems and some power will be redundant. R.W. = 9.0 R.W. * W.F. = 5.4	Proliferation of alerts and caution and warning devices tends to consume more volume. R.W. = 6.0 R.W. * W.F. = 3.6	Correlation of alert and system checklists not straightforward. Almost impossible to categorize and prioritize alerts. R.W. = 4.0 R.W. * W.F. = 4.0	Inhibiting alerts not directly controllable. R.W. = 0.0 R.W. * W.F. = 0.0	Has tendency to proliferate workstation with alerts. R.W. = 5.0 R.W. * W.F. = 3.5
INTEGRATED CAUTION AND WARNING SYSTEM	Although hardware may be reduced for the integrated system, software and systems development will create a high cost. R.W. = 8.0 R.W. * W.F. = 6.4	Cost will tend to be lower over the life cycle of the space station. R.W. = 10.0 R.W. * W.F. = 8.0	An integrated advisory, caution, and warning system will require large amounts of system and software development time thereby increasing schedule development time. R.W. = 7.0 R.W. * W.F. = 2.1	Power can be optimized by consolidating functions in an integrated system. R.W. = 10.0 R.W. * W.F. = 6.0	Consolidation of functions leads to decreased volume. R.W. = 10.0 R.W. * W.F. = 6.0	Facilitates correlation of alert and system checklists needed for checkout. Central processor software improves ability to categorize and prioritize alerts. R.W. = 10.0 R.W. * W.F. = 10.0	Non-critical alerts may be inhibited during a period of high workload. R.W. = 10.0 R.W. * W.F. = 7.0	Alerts are more easily consolidated. R.W. = 10.0 R.W. * W.F. = 7.0
Weighting factor	0.8	0.8	0.3	0.6	0.6	1.0	0.7	0.7

1 FOLDOUT FRAME

Table 2.0.4.3
Caution and Warning Trade Study

2 FOLDOUT FRAME

ORIGINAL PAGE IS OF POOR QUALITY

	PERFORMANCE (cont.)	RISK		GROWTH AND EVOLUTION	SAFETY	USER FRIENDLY	TOTALS
Options	ERGONOMICS	TECHNOLOGY SOA	AVAILABILITY	GROWTH CAPABILITY	FAILURE MODES	CREW PERFORMANCE	FIGURE OF MERIT (see Note)
DISTRIBUTED CAUTION AND WARNING SYSTEM	Difficult task to correlate alert-type applications and significance. R.W. = 4.0 R.W. * W.F. = 1.6	Technology is available and in a mature state. R.W. = 10.0 R.W. * W.F. = 3.0	The technology availability factor is relatively low. R.W. = 10.0 R.W. * W.F. = 3.0	Alerts can be added on an independent basis. R.W. = 10.0 R.W. * W.F. = 6.0	Operators may ignore alarms if he thinks it is false. R.W. = 5.0 R.W. * W.F. = 5.0	Lower overall crew member performance level due to proliferation and non-categorization of alerts. R.W. = 7.0 R.W. * W.F. = 2.8	Figure of merit $\frac{55.3}{85.0} = 65.06$
INTEGRATED CAUTION AND WARNING SYSTEM	Central processor software can easily correlate alert-types and their significance. R.W. = 10.0 R.W. * W.F. = 4.0	Technology is available, although much applications, systems integration, and software work will need to be done. R.W. = 7.0 R.W. * W.F. = 2.1	The technology availability factor is higher due to implementing a relatively new and complex concept. R.W. = 8.0 R.W. * W.F. = 2.4	Integrated system hardware/software must be modified to add, delete, or alter alerts. R.W. = 9.0 R.W. * W.F. = 5.4	A smart integrated system would prevent obvious false alarms. R.W. = 10.0 R.W. * W.F. = 10.0	Higher overall crew member performance level. R.W. = 10.0 R.W. * W.F. = 4.0	Figure of merit $\frac{80.4}{85.0} = 94.59$
Weighting factor	0.4	0.3	0.3	0.6	1.0	0.4	

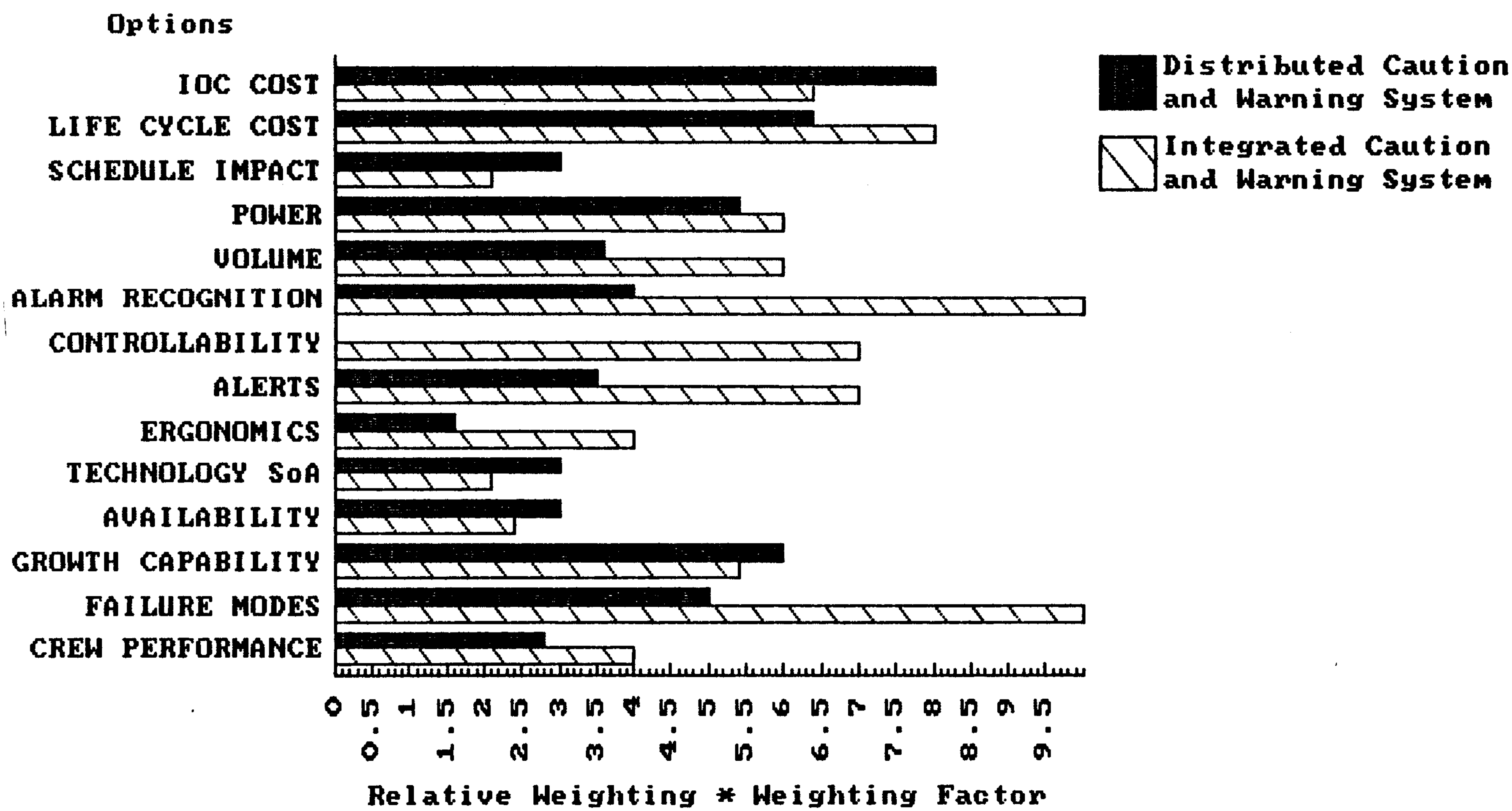
NOTE: Figure of merit = $\sum_{i=1}^{i=14} RW_i * WF_i \Big/ \sum_{i=1}^{i=14} RW_i(10) * WF_i$

Table 3.2.4.3 (cont.)
Caution and Warning Trade Study

2 FOLDOUT FRAME

1 FOLDOUT FRAME

Figure 2.0.4.3
Caution and Warning Trade Study



XV. MASS STORAGE

MASS STORAGE TRADE STUDY

1. Reason For Trade Study

Mass storage devices will be used extensively by the SSDS for both on-board and ground elements. This trade study will identify preferred options and configurations for the specific application areas that are expected to drive the system design and/or stress the available technology.

2. Background

The Space Station Program will handle, process, and store unprecedented quantities of data. This will require innovative concepts that address a wide range of data storage requirements from short-term buffering to long term archival. The type of data will also vary significantly and includes the following:

- Software
- Manuals
- Command Procedures
- Level 0 Data
- Communication (voice, video)
- Engineering Data
- Real Time Data
- Buffered Data
- Trend Data
- Diagnostics Support Data
- Etc.

While mass storage devices will be used extensively throughout the SSDS, commercially available products will satisfy many of the program needs. However, specific applications areas have been identified that are expected to be design/technology drivers. In these areas a more detailed analysis is required to identify preferred devices and configurations. Since these applications are likely to have a wide variation in requirements and architectural needs, it is likely that different technologies may be appropriate for the different applications.

The drivers for these applications are requirements (documented in the Task 1 report), derived requirements, and design characteristics. The key application areas to be addressed by this trade study are:

A. Buffering of delayable payload data both in space and on the ground
B. Short term archiving of customer data
C. On-board space station data base

Key buffering design characteristics developed from simulations of a preliminary end-to-end concept and the LaRC data base as modified by the Woods Hole update are presented in Table 1. A graphic representation of the buffering loads driven by mission needs and communication constraints is shown in figure 2. Table 1 shows that the buffering requirements are separated into three functional areas, on-board space station, on-board polar-orbiting platform (POP), and data handling center buffers. POP(1) simulation results are used as they represent the worst case POP design characteristics. Final design characteristics for each functional area will be a function of system design and will be derived during this study and in conjunction with evolving system definition concepts.

	SPACE STATION	POLAR-ORBIT PLATFORM	DATA HANDLING CENTER
CAPACITY:	2×10^{11} BITS	5.1×10^{11} BITS	10^{12} BITS
TRANSFER RATE:	300 MBITS/SEC	300 MBITS/SEC	IN:900 MBITS/SEC
BIT ERROR RATE:	$< 10^{-6}$	$< 10^{-6}$	$< 10^{-6}$
PHYSICALS:	SPACE FLIGHT CONSTRAINED	SPACE FLIGHT CONSTRAINED	NONE
RAD HARDNESS			
TOTAL DOSE:	230 RADS/YEAR	2K-25K RADS/YEAR	NONE
RELIABILITY			
MAINTAINABILITY:	MAN AVAILABLE	SPECIAL MISSION	MAN AVAILABLE

Table 1: Design characteristics for critical SSDS buffers

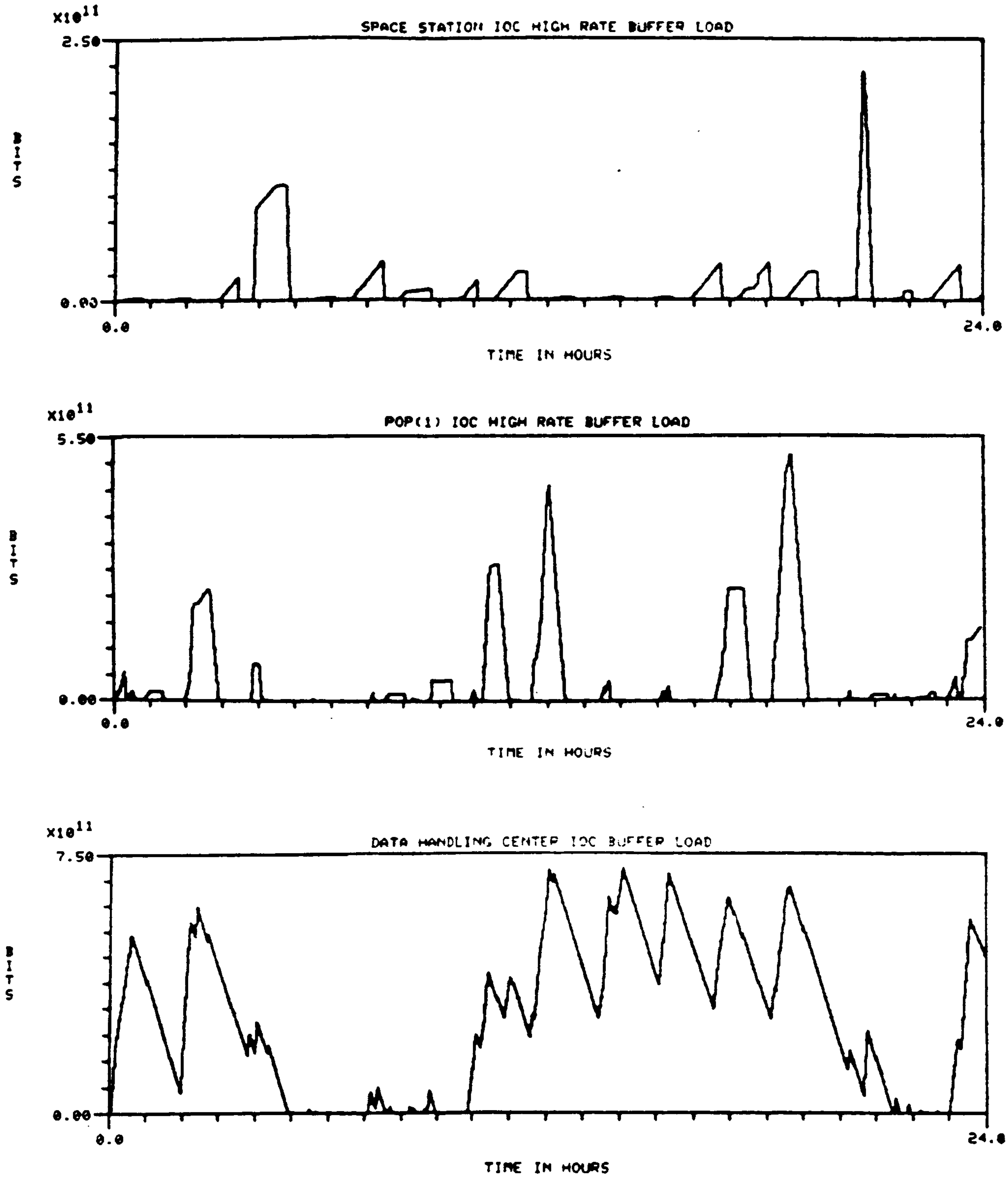


Figure 2: Plot of SSDS simulation buffer load results

Requirements for short term archiving were developed by integrating the mission set average data rate, for both IOC and growth, over the appropriate time periods. The results of this mission set analysis are given below and range from the IOC amount to the growth amount.

A. 12 hour on-line storage
   $5\text{–}8 \times 10^{12}$ bits capacity
   60 seconds access time
   Average transfer rate of 110–179 Mbits/sec

B. 7 day off-line storage
   $7\text{–}10 \times 10^{13}$ bits capacity
   Less than 24 hours access time
   Average transfer rate of 110–179 Mbits/sec

Storage of manuals and procedures, software, scheduling information, and storage for customer data are a few of the many types of data the on-board space station data base must store. As a whole, the mass storage system for the on-board data base should provide fast access to the numerous kinds of data. An analysis of the functions presented in Task 1 and the mission set indicate that the on-board data base will have the following requirements

Storage capacity of 2×10^{9} bits
Access time of 40 milliseconds
Peak transfer rate of 10 Mbits/sec

Results from the following trade studies will also have an impact on the mass storage trade study:

A. End-to end networking
B. On-board local area networking
C. Distributed data base management
D. Space communications

The results from the above trade studies will directly affect the end-to-end model used in the simulations that determine design characteristics. As the trade studies progress, the model will be refined to reflect results from other trade areas in order to obtain a consistent model.

3. Issues

The issues presented below are important because they will dictate to some extent which technologies are used for mass storage in the SSDS. This trade study will attempt to resolve these issues and determine which technologies are best suited for the SSDS.

A. Figure 3 depicts the relationship between currently available mass storage devices and the various SSDS applications. What is the risk that present devices or new technology can evolve to meet the more demanding design characteristics imposed by these SSDS applications?

B. Can a common buffer capability be developed for space station and polar-orbit platforms?

C. What kind of on-board buffering configurations are needed to handle:
   1. Merging of data from multiple sources?
   2. High peak rates of up to 500 Mbits/sec?

D. Which technology will provide the more cost effective media for the large quantity of data storage needed by the short term archiving application?

E. Which technology can provide the fast access time needed by the on-board data base and also provide the necessary capacity?

4. Trade Study Criteria

The mass storage options/configurations for each application will be evaluated using the criteria presented in table 4. Each criterion is weighted according to its overall relative importance in each application. For example, environment and reliability will be given higher weights in the polar-orbit application than in the space station application because of the man availability on the space station. After evaluating the various options to see how well they meet the design characteristics and requirements for each application they will be ranked from one to ten for each criterion. That ranking will be multiplied times the weight given to that particular criterion. Summing the results for each option gives a figure of merit that should indicate which option is best suited for use in the particular application being studied.

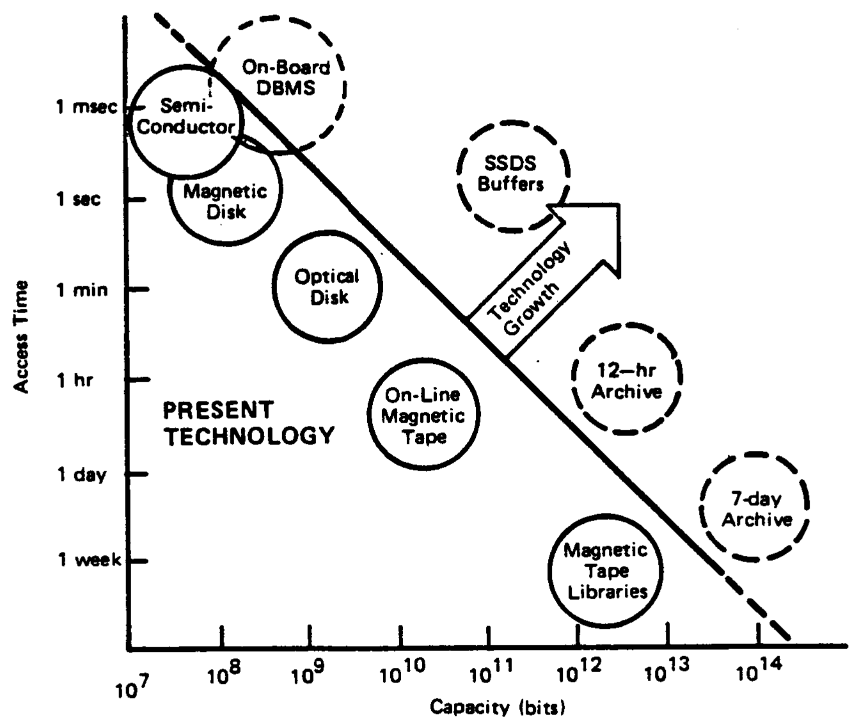


Figure 3. Relationship of Present Technology to Various SSDS Applications

CRITERIA	SPACE STATION BUFFER		POP BUFFER		DATA HANDLING CENTER		SHORT TERM ARCHIVE		SPACE STATION DATA BASE	
COST		10		10		15		20		10
—Development	4		4		4		5		4	
—Recurring	5		5		10		5		5	
—Media	1		1		1		10		1	
DEVELOPMENT RISK		15		15		15		10		15
GROWTH		15		10		20		20		15
—Extendable	7		4		12		12		7	
—Tech. Insertion	8		6		8		8		8	
RAM	15		15		20		20		15	
—Reliability	5		8		5		6		6	
—Availability	5		5		10		7		5	
—Maintainability	5		2		5		7		4	
PHYSICALS		15		15		0		0		15
—Weight	5		6		0		0		5	
—Power	10		9		0		0		10	
ENVIRONMENT		10		15		0		0		10
—Rad. Hardness	5		10		0		0		5	
—Shock & Vib.	5		5		0		0		5	
PERFORMANCE		15		15		25		25		15
—Capacity	4		4		8		8		3	
—Transfer Rate	5		5		9		5		3	
—BER	4		4		5		5		4	
—Access Time	2		2		3		7		5	
SPECIAL		5		5		5		5		5
	100	100	100	100	100	100	100	100	100	100

Table 4: Weighted set of criteria

5. Expected Results

By following the outlined methodology, the preferred mass storage device and, if applicable, configuration can be found for each of the application areas. Also, through the trade study process the issues presented in Section 3 should be resolved or result in the identification of technology deficiencies that need to be addressed by the Space Station Program.

6. Methodology

The basic approach that was taken for the trades on buffering applications consisted of the following:

A. Fully characterize the options to be traded. This was done and documented as part of Task 2.

B. Derive the design characteristics for each buffering application. As the mission model is updated, and certain end-to-end options chosen, a simulation of the end-to-end model was done to further refine the design characteristics for each buffering application. The buffering design characteristics are presented in Table 1.

C. Develop candidate configurations. Buffering of delayable data is a complex function which can be implemented in a variety of ways, thus each buffering application needs to be looked upon as a system configuration rather than simple device options. To do this, various configurations were developed that use one or more of the options (that is, different configurations may be required to make the most efficient use of a given device technology). A by-product of this step are design concepts that can be used in system definition.

D. The configurations were evaluated and ranked according to the set of criteria presented in Section 4. The result of the ranking was a figure of merit that indicated which technologies were best suited to meet the buffering design characteristics.

E. Perform a sensitivity analysis. After ranking the options, a sensitivity analysis was done to identify tradeoffs that can be made that influence the choice of option/configuration and design characteristics. The sensitivity analysis also identified major discriminators between the options and supports technology recommendations.

The approach that was taken for the short term archiving trade consists of the following:

A. Fully characterize the options to be traded. This has was done and documented as part of Task 2.

B. Derive the requirement for customer data archiving. This was done by simply integrating the mission set data rates over the appropriate time period. The requirement was refined as the mission set was modified.

C. The options were evaluated and ranked according to the set of criteria presented in Section 4. The result of the ranking was a figure of merit that indicated which technologies were best suited to meet the short term archiving requirement.

D. Perform a sensitivity analysis. After ranking the options, a sensitivity analysis was done to identify tradeoffs that can be made that influence the choice of options and design characteristics. The sensitivity analysis also identified major discriminators between the options and supports technology recommendations.

The approach that will be taken for the on-board data base trade consists of the following:

A. Fully characterize the options to be traded. This was done and documented as part of Task 2.

B. Derive the design characteristics for driving on-board data base applications. This depended on the results from the on-board system definition activity. Preliminary characteristics have been developed and are presented in Section 2.

C. The options were evaluated and ranked according to the set of criteria presented in Section 4. The result of the ranking was a figure of merit that indicated which technologies were best suited to meet the on-board DMS mass store requirement.

D. Perform a sensitivity analysis. After ranking the options, a sensitivity analysis was done to identify tradeoffs that can be made that influence the choice of options and design characteristics. The sensitivity analysis also identified major discriminators between the options and supports technology recommendations.

7. Trade Study Discussion and Results

On-Board Space Station Communication Data Buffer

Space station missions can be divided into two categories; high data rate missions and low data rate missions. For the purpose of this trade study, high data rate missions are those with a peak data rate in excess of 10 Mbits/sec. The low data rate missions are those with a peak data rate less than or equal to 10 Mbits/sec. In the on-board space station payload data communication buffer model shown in figure 5 it can be seen that there are two data buffers used to buffer the communication data. These two buffers are the high rate data buffer and the payload local area network (PLAN) communication data buffer.

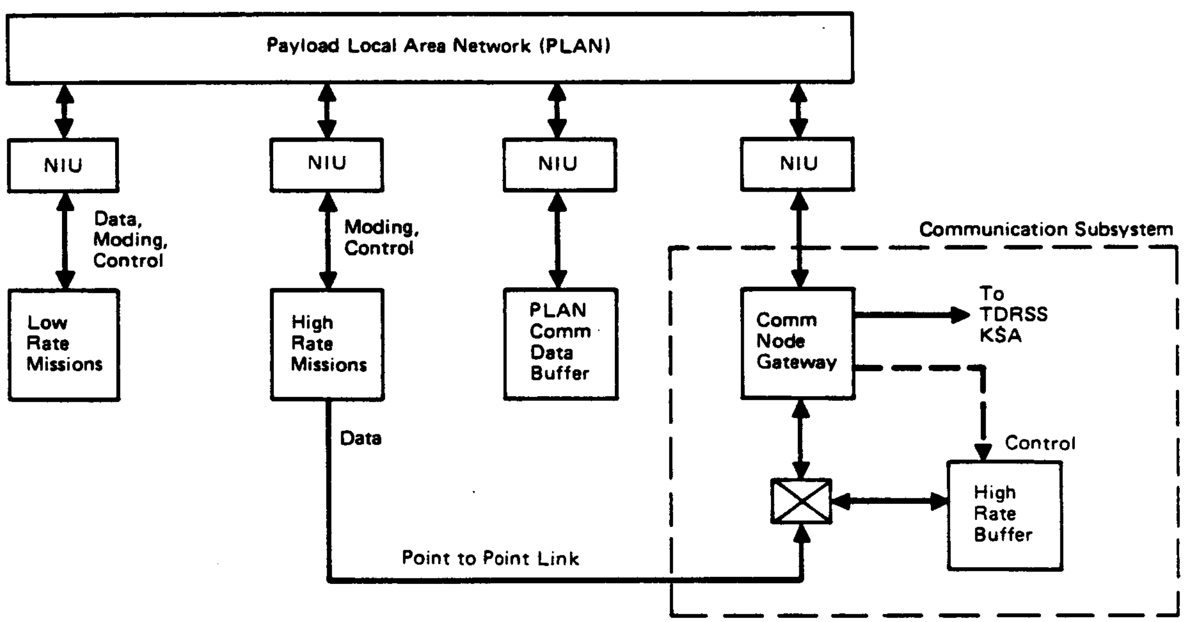


Figure 5. On-Board Space Station Payload Data Communication Buffer Model

High Rate Data Buffer

If the communication resource is not available the high rate data must be buffered in the high rate data buffer. This buffer is a resource that must be scheduled in advance. A simulation of the end-to-end model indicates the design characteristics for the high rate data buffer to be:

Capacity:	2×10^{11} Bits
Transfer Rate:	In: 300 Mbits/sec
	Out: 600 Mbits/sec*
BER:	$< 10^{-6}$
Environment:	Inside space station, 28.5° Orbit For |10 Years
Size,Wt.,Pwr.:	TBD, Space Flight Constrained
Shock & Vib.:	Non-operating Launch Survivable
Radiation:	230 Rads/year

* Assuming two KSA channels can be available

The device options for the high rate data buffer are:

1. Magnetic Tape
2. Magnetic Disk
3. Optical Disk
4. Magnetic Bubble

Magnetic Tape

The high rate buffer design characteristics could be met by one magnetic tape device, or several magnetic tape devices in the proper configuration. Although magnetic tape is serial access it is still quite versatile. Data can be recorded at one rate and played back at another. The media can be removed from the device and transported to the ground via STS when extra data security is needed or sufficent TDRSS bandwidth is not available. Magnetic tape is also a mature mass storage device that has been used in space missions since the start of the space program.

Even though the design characteristics for the high rate buffer can be implemented using only one magnetic tape device it is more desirable to use an arrangement consisting of three magnetic tape devices. The advantages of the three device arrangement over a single device include:

1. Simultaneous record and playback
2. Redundancy that improves system reliability
3. Less Sophisticated device (don't have to push the technology as hard)
4. Modularity that enhances growth capability

The three device high rate buffer system would have the following characteristics:

Capacity:	2×10^{11} Bits/system
	6.6×10^{10} Bits/device
Transfer Rate:	300 Mbits/sec/device
Device Type:	Rotary
BER:	10^{-8}/device
Rad Hardness	Good
Volume	10,000 Inches^3/system
Weight	300 Lbs/system
Power	500 Watts Peak/system
Recurring Cost*	$750,000/system
Risk	Low
Reliability	Proven High Reliability
Maintainability	Moderate Maintenance Required

* All costs are relative for similar flight-qualified devices on the assumption that space qualification cost is a constant factor times the device cost. This was done so that all the options can be compared at the same level.

The limitations of using magnetic tape include:

1. Magnetic tape is serial access
2. Future technology insertion of a random access device is constrained
3. Moving parts that are less reliable than that of solid state devices

Magnetic Disk

A high rate data buffer designed using the projected space qualified magnetic disk devices would have the following characteristics:

Capacity:	2×10^{11} Bits/system
	$3X10^{9}$ Bits/device
Number of devices:	67
Transfer Rate:	20 Mbits/sec/device
BER	10^{-8}
Peak power:	13,400 watts/system, 200 Watts/device
Recurring Cost*:	$751,212/system
Volume:	40,200 inches^3/system
Weight:	3350 lbs/system
Development Risk:	Medium
Radiation Hardness:	Good
Reliability:	Consistent with a device with moving parts
Maintenance:	Extensive

* Cost does not include space qualification cost

A single magnetic disk device cannot meet the transfer rate design characteristic. It is questionable that a method of paralleling the devices together to achieve the transfer rate design characteristic can be devised. Also, the weight and power characteristics quickly rule out the use of magnetic disk as the high rate data buffer.

Eraseable Optical Disk

Eraseable optical disk is a relativly new technology that has most of the characteristics that would make it a candidate for the high rate data buffer. Optical disk devices have high capacity and fast data transfer rates. Currently they are non-erasable, which would make them unsuitable for use in the high data turnover application of data buffering. Techniques have been developed and demonstrated that would give the optical disk eraseability. RCA is one company that has been doing extensive work in the optical disk field. They currently have two non-eraseable optical disk jukeboxes installations; one at Langley Research Center and the other at Rome Air Development Center.

RCA has proposed an "Optical Disk Buffer" that would employ an eraseable magneto-optic technique to produce a buffer that would have a large capacity and fast data transfer rate in a relativly small package. The "Optical Disk Buffer" would have the following characteristics:

Capacity:	10^{12} Bits
Transfer Rate:	1000 Mbits/sec
Power:	500 Watts Average
Volume:	61,000 Inches^3
Weight:	700 lbs
Recurring Cost*:	TBD (A Price model indicates $10,000,000 for a space qualified device)
Radiation Hardness:	TBD (Should be good)
Risk:	Medium High
Reliability:	Consistent with a device with moving parts
Maintainability:	TBD

* Price does include space qualification cost

Because eraseable optical disk is a new technology the development risk is much higher than that of magnetic tape, but the technology for the "Optical Disk Buffer" has been demonstrated in the lab, and with the proper funding the device can be developed and ready for use in the 1992 space station.

Bubble Memory

A high rate data buffer designed using magnetic bubble memory would have the following characteristics:

Capacity:	2×10^{11} Bits/system
	16×10^{6} Bits/device
Device Count:	12,500
Transfer Rate:	400 Kbits/sec/device
Number of Devices Needed To Achieve Design Characteristic	
Transfer Rate:	750
BER:	10^{-14}
Peak Power:	8 watts/device
	> 6000 watt at 300 Mbits/sec
Weight:	2,500 lbs/system
Volume:	75,000 Inches^3/system
Cost*:	$1,250,000/system
Development Risk:	Medium
Radiation Hardness:	TBD (depends on current development efforts)
Reliability:	Very Good (solid state device)
Maintainability	Moderate, modular replacement of devices.

As with magnetic disk, it would take too many of the magnetic bubble devices to construct the high rate data buffer. The system cost, weight, volume, and power would be far too much.

On-Board Space Station High Rate Buffer Results

After assessing the various options to see how well they would fit into the space station high rate buffer the options were ranked from one to ten (ten being best) for each criterion. Table 6 presents the results of the rankings. Magnetic disk and magnetic bubble are not qualified for use as the space station high rate buffer because of poor physical characteristics. This leaves magnetic tape and optical disk as candidates for the space station high rate buffer.

CRITERIA	WEIGHT	MAGNETIC TAPE	TOTAL	MAGNETIC DISK	TOTAL	OPTICAL DISK	TOTAL	MAGNETIC BUBBLE	TOTAL
		OPTIONS							
COST									
DEVELOPMENT:	4	10	40	8	32	7	28	9	36
RECURRING:	5	9	45	8	40	6	30	7	35
MEDIA:	1	7	7	10	10	8	8	9	9
DEVL. RISK:	15	10	150	9	135	7	105	8	120
GROWTH									
EXTENDABLE:	7	9	63	8	56	7	49	10	70
INSERTABLE:	8	8	64	10	80	9	72	7	56
RAM									
RELIABILITY:	5	7	35	8	40	9	45	10	50
AVAILABILTY:	5	9	45	7	35	8	40	10	50
MAINTAINABILITY:	5	7	35	8	40	10	50	9	45
PHYSICALS									
WEIGHT:	5	10	50	3	15	8	40	4	20
POWER:	10	10	100	4	40	9	90	3	30
ENVIRONMENT									
RAD HARDNESS:	5	9	45	9	45	9	45	6	30
SHOCK & VIB:	5	9	45	7	35	8	40	10	50
PERFORMANCE									
CAPACITY:	4	10	40	6	24	9	36	7	28
TRANSFER RATE:	5	8	40	4	20	10	50	6	30
BER:	4	8	32	9	36	7	28	10	40
ACCESS TIME:	2	6	12	8	16	10	20	9	18
SPECIAL:	5	0	0	7	35	10	50	6	30
TOTALS	100		848		734		826		747

TABLE 6: ON-BOARD SPACE STATION HIGH RATE BUFFER

The most significant discriminators between magnetic tape and optical disk are:

1. Development Risk
2. Special Considerations

Magnetic tape is a mature mass storage device that has been used since the start of the space program. Today it is still used almost exclusively for spaceborn mass data storage. If magnetic tape is selected to be used as the space station high rate data buffer the major development effort will be in pushing the data rate up to 300 Mbits/sec. This data rate can be met with the longitudinal recording method at the expense of power and weight, or the data rate can be met with the newer, not as mature, rotary recording method.

Random access and a capability to simultaneously record and playback several channels of high rate data are the optical disk's main advantages. This eliminates bit reversal problems asssociated with some magnetic tape techniques. The development risk of an optical disk high rate buffer is high. The major techniques involved with the magneto–optic technique that this buffer would use have already been demonstrated, but a lack of funding has slowed down the development effort. If proper funding is supplied up front, the development risk for the optical disk buffer could go down considerably. Some of the potential payoffs for doing this include:

1. A buffering device with random access
2. No need to incur the extra cost of inserting the optical disk technology at a later date.
3. Improved performance of the buffering system over magnetic tape.

Space Station High Rate Buffer Recommendations

It is recommended that advanced development efforts be focused on eraseable optical disk technology for this buffering application to reduce the perceived risk associated with this option. With sufficient emphasis this technology could be demonstrated and considered for the IOC configuration. If such emphasis is not provided, magnetic tape provides a mature base for IOC, however, eraseable optical disk development should continue for insertion into the growth space station because of the benefits it can provide.

Space Station Payload Local Area Network (PLAN) Communication Data Buffer

An estimate of the design characteristics for the PLAN communication data buffer was obtained by buffering the total average data rate of all the low rate missions for one orbit. The sum of all the IOC low rate missions, including the co-orbiting platform mission, is 2.175 Mbits/sec. Integrating that over one 90 minute orbit results in the need to buffer 12 x 10^9 bits of data. The full design characteristics for the PLAN communication data buffer are:

Capacity: 12 X 10^9 bits

Transfer Rate: 10 Mbits/second

BER: $< 10^{-6}$

Environment: Inside space station, 28.5° orbit for | 10 years

Size, Wt., Pwr.: TBD, space flight constrained

Shock & Vib.: Non-operating launch surviable

Radiation: 230 Rads/year

The device options for the PLAN communication data buffer are:

1. Magnetic Tape
2. Magnetic Disk
3. Optical Disk
4. Bubble Memory

Magnetic Tape:

The PLAN communication data buffer can be built with present technology. An Odetics DDS-6000 Spacelab magnetic tape recorder is one example of a space qualified device that could meet the design characteristics of the PLAN communication data buffer. The specifications for the DDS-6000 are:

Capacity:	3.84×10^{10} bits
Transfer Rate:	32 Mbits/second
BER:	10^{-6}
Device Type:	Longitudinal
Rad Hardness:	Good
Shock & Vib.:	Space Qualified
Weight:	105 lbs
Volume:	4000 inches^3
Power:	174 Watts Peak
Recurring Cost:	$1,500,000*
Development Risk:	Low
Reliability:	Good
Maintainability:	Moderate maintenance required

* Cost for Space qualified device only

The device presented above has good performance figures, but because it is a serial access device, the buffer would have to operate as a first in, first out type of device thus preventing an implementation of a priority transmission scheme.

Magnetic Disk

A PLAN communication data buffer designed with projected magnetic disk capabilities would have the following characteristics:

Capacity:	12×10^9 bits/system
Transfer Rate:	20 Mbits/second/system
# of Devices:	4
BER	$< 10^{-10}$
Volume:	2400 inches^3/system
Weight:	200 lbs/system
Power:	800 Watts Peak/system
Recurring Cost:	$44,400/system
Development Risk	Medium
Reliability:	Consistent with a non-solid state device
Maintainability:	Moderate maintenance required

The projected magnetic disk device has good performance figures, but it also has a high power requirement.

Optical Disk

If development of the "Optical Disk Buffer" proceeds as recommended in the section on the on-board space station high rate buffer then a smaller capacity optical buffer could be developed out of the same program for use as the PLAN communication data buffer. The characteristics of such a buffer could be:

Capacity:	8×10^{10} bits
Transfer Rate:	100 Mbits/sec
Power:	200 Watts average
Volume:	5100 inches^3
Weight:	200 lbs
Cost*:	TBD (rough order of magnitude: $1,000,000)
Rad Hardness:	TBD (good)
Development Risk:	Medium high
Reliability:	Consistent with a device with moving parts
Maintainability:	TBD

* Price <u>does</u> include space qualification cost.

Because eraseable optical disk is a new technology, the development risk is much higher than that of magnetic tape, but the technology for the "Optical Disk Buffer" has been demonstrated in the lab, and with proper funding the device can be developed and ready for use in the 1992 space station.

Bubble Memory

A PLAN communication data buffer designed using magnetic bubble would have the following characteristics:

Capacity:	12×10^{9} bits
Transfer Rate:	10 Mbits/second
Number of devices needed to achieve transfer rate:	25
Power:	8 Watts/device Peak
	> 200 Watts/system at 10 Mbits/sec
Weight:	150 lbs
Volume:	4500 $inches^{3}$
Recurring Cost*:	$75,000
Development Risk:	Medium
Rad Hardness:	TBD (depends on current development effort)
Reliability:	Very good (solid state device)
Maintainability:	Moderate, Modular replacement of devices

* does not include space qualification cost

Bubble memory has good characteristics in all but one area, radiation hardness. Current bubble memory support electronics use a Metal-Oxide-Semiconductor technology that is not radiation hard. The USAF currently has a development program to produce a space qualified chip set that may have potential application in space.

Space Station PLAN Communication Data Buffer Results

After assessing the various options to see how well they would fit into the space station PLAN communicaion data buffer, the options were ranked from one to ten (ten being best) for each criterion. Table 7 presents the results of the ranking.

All of the candidate options are capable of serving as the space station PLAN communication data buffer. The major discriminators between the options are:

1. Cost
2. Development Risk
3. Power Requirements
4. Performance
5. Special Considerations

Magnetic tape is the most mature of the options, thus it has a lower cost and development risk. Sequential access is a major drawback to the use of magnetic tape as a data buffer. Because of the sequential access characteristic a priority transmission of buffered data scheme is not possable.

Magnetic disk has adequate performance and growth potential, but unless unless its power requirements can be lowered it should not be considered as an option for the PLAN communication buffer.

Optical disk has very good performance figures. It offers excess capacity on the order of 7.6 times the desired design characteristic, thus giving plenty of capacity for use in the growth configuration. A special consideration is the random access characteristic of optical disk thus providing improved performance and the ability to implement a scheme to have priority transmission of buffered data.

Eraseable optical disk has a high development risk because it is an emerging technology, but the technology has been demonstrated in the laboratory with promising results. The development risk and cost will be reduced if the PLAN communictaion data buffer and the space station high rate data buffer share the same optical disk development effort. By sharing the development effort the risk could be significantly reduced because of the increased funding that could be available. This shared development effort can also lead to device commonality that would further reduce overall costs.

CRITERIA	WEIGHT	MAGNETIC TAPE	TOTAL	MAGNETIC DISK	TOTAL	OPTICAL DISK	TOTAL	MAGNETIC BUBBLE	TOTAL
COST									
DEVELOPMENT:	4	10	40	8	32	7	28	9	36
RECURRING:	5	10	50	9	45	7	35	8	40
MEDIA:	1	7	7	10	10	8	8	9	9
DEVL. RISK:	15	10	150	9	135	7	105	8	120
GROWTH									
EXTENDABLE:	7	9	63	8	56	7	49	10	70
INSERTABLE:	8	7	56	9	72	10	80	8	64
RAM									
RELIABILITY:	5	8	40	7	35	9	45	10	50
AVAILABILTY:	5	7	35	8	40	10	50	9	45
MAINTAINABILITY:	5	8	40	7	35	9	45	10	50
PHYSICALS									
WEIGHT	5	10	50	8	40	8	40	9	45
POWER:	10	10	100	7	70	9	90	8	80
ENVIRONMENT									
RAD HARDNESS:	5	9	45	9	45	9	45	6	30
SHOCK & VIB:	5	9	45	7	35	8	40	10	50
PERFORMANCE									
CAPACITY:	4	9	36	7	28	10	40	6	24
TRANSFER RATE:	5	9	45	8	40	10	50	6	30
BER:	4	8	32	9	36	7	28	8	32
ACCESS TIME:	2	6	12	8	16	10	20	9	18
SPECIAL:	5	0	0	7	35	10	50	6	30
TOTALS	100		846		805		848		823

(OPTIONS spans the four option column groups.)

TABLE 7: ON-BOARD SPACE STATION PLAN COMMUNICATION DATA BUFFER

Bubble memory has a good figure of merit, but it falls short in the areas of performance and radiation hardness. A current Air Force development program might give the bubble memory potential for use this applications.

<u>Space Station PLAN Communication Data Buffer Recommendations</u>

It is recommended that advanced development efforts be focused on eraseable optical disk technology for this buffering application to reduce the perceived risk associated with this option. Furthermore, this development effort should be part of the same development effort that is recommended for the space station high rate data buffer. This will reduce overall development cost and increase optical disk development funding that would tend to further reduce the eraseable optical disk development risk.

If the eraseable optical disk development does not proceed as recommended, magnetic tape can be brought into the IOC configuration at a later date because of it's maturity. However, optical disk development should continue for insertion into the growth space station because of the benefits it can provide.

On-Board Polar-Orbit Platform (POP) Communication Data Buffer

A simulation of the end-to-end model indicates the design characteristics for the worst case POP data buffer to be:

Capacity:	5.1×10^{11} Bits
Transfer Rate:	300 Mbits/sec
BER:	$< 10^{-6}$
Environment:	On POP 90^{o} Orbit For |10 Years
Size,Wt.,Pwr.:	TBD, Space Flight Constrained
Shock & Vib.:	Non-operating Launch Survivable
Radiation:	2K - 25k Rads/year

The device options for the POP data buffer include:

1. Magnetic Tape
2. Magnetic Disk
3. Optical Disk
4. Magnetic Bubble

Magnetic Tape

The POP buffer design characteristics could be met by one magnetic tape device, or several magnetic tape devices in the proper configuration. Although magnetic tape is serial access it is still quite versatile. Data can be recorded at one rate and played back at another. Magnetic tape is also a mature mass storage device that has been used in space missions since the start of the space program.

Even though the design characteristics for the POP buffer can be implemented using only one magnetic tape device it is more desirable to use an arrangement consisting of three magnetic tape devices. The advantages of the three device arrangement over a single device include:

1. Simultaneous record and playback
2. Redundancy that improves system reliability
3. Less Sophisticated device (don't have to push the technology as hard)
4. Modularity that enhances growth capability

The three device POP buffer would have the following characteristics:

Capacity:	5.1×10^{11} Bits/system
	1.7×10^{11} Bits/device
Transfer Rate:	300 Mbits/sec/device
Device Type:	Rotary
BER:	10^{-8}/device
Rad Hardness	Good
Volume	10,000 Inches^3/system
Weight	300 Lbs/system
Power	500 Watts Peak/system
Recurring Cost*	$750,000/system
Risk	Low
Reliability	Proven High Reliability
Maintainability	Moderate Maintenance Required

* Most costs are for similar flight-qualified devices on the assumption that space qualification cost is a constant factor times the device cost. This was done so that all the options can be compared at the same level.

The limitations of using magnetic tape include:

1. Magnetic tape is serial access
2. Future technology insertion of a random access device
3. Moving parts that are less reliable than that of solid state devices

Magnetic Disk

A POP data buffer designed using the projected space qualified magnetic disk device would have the following characteristics:

Capacity:	5.1×10^{11} Bits/system
	3×10^{9} Bits/device
Number of devices:	170
Transfer Rate:	20 Mbits/sec/device
BER	10^{-8}
Peak power:	34,000 watts/system, 200 Watts/device
Recurring Cost*:	$1,906,000/system
Volume:	102,000 inches^3/system
Weight:	8500 lbs/system
Development Risk:	Medium
Radiation Hardness:	Good
Reliability:	Consistent with a device with moving parts
Maintenance:	Extensive

* Cost does not include space qualification cost

A single magnetic disk device cannot meet the transfer rate design characteristic. It is questionable that a method of paralleling the devices together to achieve the transfer rate design characteristic can be devised. Also, the weight and power characteristics quickly rule out the use of magnetic disk as the POP data buffer.

Eraseable Optical Disk

Eraseable optical disk is a relativly new technology that has most of the characteristics that would make it a candidate for the POP data buffer. Optical disk devices have high capacity and fast data transfer rates. Currently they are non-erasable, which would make them unsuitable for use in the high data turnover application of data buffering, but techniques have been developed and demonstrated that would give the optical disk eraseability. RCA is one company that has been doing extensive work in the optical disk field. They currently have two optical disk jukeboxes installations; one at Langley

Research Center and the other at Rome Air Development Center. RCA has proposed an "Optical Disk Buffer" that would employ a magneto-optic technique to produce a buffer that would have a large capacity and fast data transfer rate in a relativly small package. The "Optical Disk Buffer" would have the following characteristics:

Capacity:	10^{12} Bits
Transfer Rate:	1000 Mbits/sec
Power:	500 Watts Average
Volume:	61,000 Inches^3
Weight:	700 lbs
Cost:	TBD (A Price model indicates $10,000,000 for a space qualified device)
Radiation Hardness:	TBD (Should be good)
Risk:	Medium High
Reliability:	Consistent with a device with moving parts
Maintainability:	TBD

Because eraseable optical disk is a new technology the development risk is much higher than that of magnetic tape, but the technology for the "Optical Disk Buffer" has been demonstrated in the lab, and with the proper funding the device can be developed and ready for use in the 1992 Space Station Program.

Bubble Memory

A POP data buffer designed using magnetic bubble memory would have the following characteristics:

Capacity:	5.1×10^{11} Bits/system
	16×10^{6} Bits/device
Device Count:	31,875
Transfer Rate:	400 Kbits/sec/device
Number of Devices Needed To Achieve Design Characteristic	
Transfer Rate:	750
BER:	10^{-14}
Peak Power:	8 watts/device
	$>$6000 watt at 300 Mbits/sec
Weight:	6375 lbs/system
Volume:	191,250 Inches^3/system
Cost*:	$3,187,000/system
Development Risk:	High
Radiation Hardness:	TBD (depends on current development efforts)
Reliability:	Very Good (solid state device)
Maintainability	Moderate, modular replacement of devices.

As with magnetic disk, it would take too many of the magnetic bubble devices to construct the POP data buffer. The system cost, weight, volume, and power would be far too much.

On-Board POP Communication Data Buffer Results

After assessing the various options to see how well they would fit into the POP communication data buffer the options were ranked from one to ten (ten being best) for each criterion. Table 8 presents the results of the ranking. Magnetic disk and magnetic bubble are not qualified for use as the POP communication data buffer because of poor physical characteristics. This leaves magnetic tape and optical disk as candidates for the POP communication data buffer.

		OPTIONS							
CRITERIA	WEIGHT	MAGNETIC TAPE	TOTAL	MAGNETIC DISK	TOTAL	OPTICAL DISK	TOTAL	MAGNETIC BUBBLE	TOTAL
COST									
DEVELOPMENT:	4	10	40	8	32	7	28	9	36
RECURRING:	5	9	45	8	40	6	30	7	35
MEDIA:	1	7	7	10	10	8	8	9	9
DEVL. RISK:	15	10	150	9	135	7	105	8	120
GROWTH									
EXTENDABLE:	4	9	36	8	32	7	28	10	40
INSERTABLE:	6	8	48	10	60	9	54	7	42
RAM									
RELIABILITY:	8	7	56	8	64	9	72	10	80
AVAILABILTY:	5	7	35	8	40	10	50	9	45
MAINTAINABILITY:	2	9	18	7	14	8	16	10	20
PHYSICALS									
WEIGHT:	6	10	60	3	18	8	48	4	24
POWER:	9	10	90	4	36	9	81	3	27
ENVIRONMENT									
RAD HARDNESS:	10	9	90	9	90	9	90	6	60
SHOCK & VIB:	5	9	45	7	35	8	40	10	50
PERFORMANCE									
CAPACITY:	4	10	40	6	24	9	36	7	28
TRANSFER RATE:	5	9	45	4	20	10	50	6	30
BER:	4	8	32	9	36	7	28	10	40
ACCESS TIME:	2	6	12	8	16	10	20	9	18
SPECIAL:	5	0	0	7	35	10	50	6	30
TOTALS	100		849		737		834		734

TABLE 8: ON-BOARD POLAR-ORBIT PLATFORM COMMUNICATION DATA BUFFER

The most significant discriminators between magnetic tape and optical disk are:

1. Development Risk
2. Special Considerations

Magnetic tape is a mature mass storage device that has been used since the start of the space program. Today it is still used almost exclusively for spaceborn mass data storage. If magnetic tape is selected to be used as the space station high rate data buffer the major development effort will be in pushing the data rate up to 300 Mbits/sec.

Random access and a capability to simultaneously record and playback several channels of high rate data are the optical disk's main advantages. This eliminates bit reversal problems asssociated with some magnetic tape techniques. The development risk of an optical disk high rate buffer is high. The major techniques involved with the magneto–optic technique that this buffer would use have already been demonstrated, but a lack of funding has slowed down the development effort. If proper funding is supplied up front, the development risk for the optical disk buffer could go down considerably. Some of the potential payoffs for doing this include:

1. A buffering device with random access
2. No need to incur the extra cost of inserting the optical disk technology at a later date.
3. Improved performance of the buffering system over magnetic tape.

<u>POP Communication Data Buffer Recommendations</u>

It is recommended that advanced development efforts be focused on eraseable optical disk technology for this buffering application to reduce the perceived risk associated with this option. Furthermore, this development effort should be part of the same development effort that is recommended for the space station high rate data buffer. This will reduce overall development cost and increase optical disk development funding that would tend to further reduce the eraseable optical disk development risk. If the eraseable optical disk development does not proceed as recommended, magnetic tape can be brought into the IOC configuration at a later date because of it's maturity. However, optical disk development should continue for insertion into the growth Space Station Program because of the benefits it can provide.

Data Handling Center Buffer

The data handling center buffer will need to buffer data coming from the TDRSS KSA communication links at rates up to 900 Mbits/second. A computer simulation of the end-to-end model determined that it is necessary to buffer 10^{12} bits of high rate data. Assuming TDRSS uses three KSA links evenly, a separate buffer with a capacity of 3.3×10^{11} bits and a transfer rate of 300 Mbits/sec will be allocated for each TDRSS KSA link. Therefore the design characteristics for a common TDRSS KSA buffer will be:

3.3×10^{11} bits capacity
300 Mbits/second transfer rate
BER $< 10^{-6}$

The options for the data handling center buffer are:

1. Magnetic Tape
2. Magnetic Disk
3. Optical Disk

Magnetic Tape

To design the data handling center buffer using magnetic tape would require a configuration of three magnetic tape devices per KSA link. One device to record, one device to playback, and one device would be in between the two operations. The characteristics of such a device should include:

1. 110 Gbits capacity
2. Data transfer rate of up to 300 Mbits/second
3. Variable playback rate.

It is predicted that such a high performance device can be built and would carry a price tag of over 1 million dollars each. In this scheme all data would be processed first in first out, thus not allowing any priority level 0 processing on the ground. Over the full range of criteria magnetic tape appears to be a good candidate for the data handling center buffer.

Magnetic Disk

Because of the requirement to record at 300 Mbits/sec magnetic disk might not be able to be used as the data handling center buffer. Predicted magnetic disk devices will only achieve a transfer rate of around 40 Mbits/sec. The only way magnetic disk could be used is if the data is split into manageable streams around 40 Mbits/sec. This is possible if real time processing to split the data into streams of complete packets is done as the data is received from the TDRSS KSA link. To buffer the expected 330 Gbits of data would require 10 devices with a capacity of 33 Gbits each. The total cost for these 10 device would be approximately 1 million dollars.

Optical Disk

The RCA "Optical Disk Buffer" proposed for the on-board space station data buffer would also have use in the data handling center buffer application. The "Optical Disk Buffer" characteristics of 10^{12} bits capacity and and 10^{9} bits/sec transfer rate make the "Optical Disk Buffer" an ideal candidate for the data handling center buffer. Drawbacks to the use of the eraseable optical disk buffer include a high development risk because of the newness of the technology. This risk can be brought down if the "Optical Disk Buffer" is developed for both the on-board space station buffer application and the data handling center buffer application. This would happen because additional development funding could be supplied to support this common capability.

Data Handling Center Results

After assessing the various options to see how well they would fit into the data handling center buffer application the options were ranked from one to ten (ten being best) for each criterion. Table 9 presents the results of the ranking. Execept for magnetic disk in transfer rate and magnetic tape in access time, all three options scored well in all criteria.

Magnetic tape scored well in the criteria of cost and development risk. The access time to data should not pose a problem if a first in, first out buffering scheme is used. A priority processing scheme is not possible with magnetic tape.

CRITERIA	WEIGHT	OPTIONS: MAGNETIC TAPE	TOTAL	MAGNETIC DISK	TOTAL	OPTICAL DISK	TOTAL
COST							
DEVELOPMENT:	4	10	40	9	36	7	28
RECURRING:	10	10	100	8	80	9	90
MEDIA:	1	8	8	10	10	9	9
DEVL. RISK:	15	10	150	9	135	8	120
GROWTH							
EXTENDABLE:	12	10	120	9	108	8	96
INSERTABLE:	8	9	72	10	80	8	64
RAM							
RELIABILITY:	5	8	40	9	45	10	50
AVAILABILTY:	10	8	80	9	90	10	100
MAINTAINABILITY:	5	10	50	8	40	9	45
PERFORMANCE							
CAPACITY:	8	9	72	8	64	10	80
TRANSFER RATE:	9	9	81	6	54	10	90
BER:	5	9	45	10	50	8	40
ACCESS TIME:	3	6	18	9	27	10	30
SPECIAL:	5		0	8	40	10	50
TOTALS	100		876		859		892

TABLE 9: DATA HANDLING CENTER BUFFER

Magnetic disk scored good marks in all criteria except transfer rate. This could be a problem if real time splitting of the data into 40 Mbit/sec data streams is not possible.

Optical disk has the best figure of merit. It scored well in the performance and RAM criteria. Development risk is a major discriminator against optical disk. If optical disk is developed in parallel for both the data handling center and on-board space station high rate buffer applications the development risk could be significantly reduced because of the added development funding it could receive.

Data Handling Center Buffer Recommendations

It is recommended that advanced development efforts be focused on optical disk technology for buffering applications to reduce the perceived risk associated with this option. The development risk is further reduced by parallel development of the optical disk buffer for both the space station on-board buffer and the data handling center buffer applications. With sufficient emphasis this technology could be demonstrated and considered for the IOC configuration. If the optical disk development does not proceed as recommended, magnetic tape should be as the IOC option because of its maturity. However, optical disk development should continue for insertion into the growth configuration of the data handling center buffer application.

Magnetic disk is not recommended as an option for the data handling center buffer applications because of the problems assocated with trying to split the TDRSS KSA link into 40 Mbits/sec stream. Splitting of packets into the separate streams is the most major of these problems.

Short Term Customer Data Archive

Requirements for a centralized short term archive were developed by integrating the mission set average data rate over the appropriate period for both IOC and growth. The results from this analysis are shown below and range from the IOC amount to the growth amount.

12 Hour On-line Storage
110 - 179 Mbits/sec average rate
5 - 8 X 10^{12} bits capacity
60 second access time (desired)

7 day off-line storage
110 - 179 Mbit/sec average transfer rate
7 - 10 X 10^{13} bits capacity
Less than 24 hours access time

The options to be considered for the short term archive are:

1. Magnetic Tape
2. Magnetic Disk
3. Optical Disk

Magnetic Tape

A short term archive designed with magnetic tape devices can meet the capacity and transfer rate requirements, but there are problems that would arise from using magnetic tape that include:

1. A long access time because of magnetic tapes sequential access characteristic. The access time can be improved if shorter tapes with less capacity are used but the tradeoff would be additional devices to make up the capacity requirement. The cost of such an arrangement, assuming tape drives with a capacity of 10^{11} bits, would be in excess of 50 million dollars. This would be a costly solution to the access time problem of magnetic tape.

2. A magnetic tape solution to the short term archive would require many man-hours of labor to do such things as remove and replace tapes from the drives, degauss and inspect the tapes, and monitor the system.

3. Access contention could be a problem if two users data are on the same magnetic tape and they request their data at the same time.

Even though magnetic tape archives exist now it is not recommended that magnetic tape be used in this application. The major reason for this is the problems caused by the sequential access characteristic of the magnetic tape devices.

Magnetic Disk

Magnetic disk provides the random access characteristic that is needed to meet the access time requirement, but it fails to provide the necessary transfer rate. This problem can be worked around by splitting the data into streams of a manageable 40 Mbits/sec. To meet the capacity requirement would require about 140 drives, at a cost of $100,000 per drive. This amounts to 14 million dollars in hardware. Assuming these devices have removable disk packs that store 35 Gbits apiece, it would take about 2900 disk packs, at $900 each to meet the 7 day capacity requirement. That amounts to a media cost of 2.6 million dollars. Because of the above reasons, it is not recommended that magnetic disk be used for the short term archiving applications.

Optical Disk

Write once optical disk provides the capacity, transfer rate, and random access needed for the short term archive. A currently operating RCA "Optical Disk Jukebox" installed at Marshall Space Flight Center has the following characteristics:

Storage for 10^{13} bits
50 Mbit/sec transfer rate
5.5 second random access to any information
Approximately $2,000,000 recurring cost

The characteristics of the optical disk jukebox are very close to the 12 hour on-line archiving requirements, thus making the optical disk jukebox concept a very attractive candidate for use as the short term archive. Major advantages to using the optical disk jukebox include:

1. Meet the on-line capacity requirement in one device.
2. Random access characteristic of optical disk.
3. Lower cost than magnetic tape or magnetic disk.
4. Low development risk. Present device characteristics almost match on-line requirments
5. Data may be transferred to a permanent archive via removable media.
6. Low media cost.

Low media cost is an advantage optical disk has over other options. It is predicted in the options development report on mass storage that an optical disk with a capacity of 533 X 10^9 bits will cost $30. To meet the seven day requirement about 190 disks are needed, which amounts to $5700. This is far less than the 2.6 million dollar media cost for the magnetic disk option.

The present "Optical Disk Jukebox" is designed to hold 128 disks. A future "Jukebox" could be designed to hold all of the 190 disks required for the 7 day archive, thus giving the 7 day archive an on-line capability. Also RCA has done a preliminary design of an automated "Optical Disk Library". This library would use the same optical disks that are used in the "Jukebox". This would allow the optical disks to be transferred from the "Optical Disk Jukebox" to permanate storage in the "Optical Disk Library".

Present optical disk transfer rate is too low to meet the requirement of 110 Mbits/sec at IOC and 179 Mbits/sec at growth, but the risk is low that development efforts will provide the necessary transfer rate.

<u>Short Term Customer Data Archiving Results</u>

Table 10 presents the results of the option ranking for the short term archiving application. Optical disk is the clear choice for use as the mass store device for the 12 hour on-line and 7 day off-line customer data archiving applications. Major discriminators for optical disk and against magnetic tape and magnetic disk are performance, device cost, and media cost.

CRITERIA	WEIGHT	MAGNETIC TAPE	TOTAL	MAGNETIC DISK	TOTAL	OPTICAL DISK	TOTAL
		OPTIONS					
COST							
DEVELOPMENT:	5	10	50	9	45	7	35
RECURRING:	5	7	35	6	30	9	45
MEDIA:	10	8	80	5	50	10	100
DEVL. RISK:	10	9	90	7	70	8	80
GROWTH							
EXTENDABLE:	12	8	96	7	84	10	120
INSERTABLE:	8	6	48	7	56	8	64
RAM							
RELIABILITY:	6	8	48	9	54	10	60
AVAILABILTY:	7	5	35	9	63	10	70
MAINTAINABILITY:	7	10	70	8	56	9	63
PERFORMANCE							
CAPACITY:	8	9	72	5	40	10	80
TRANSFER RATE:	5	9	45	6	30	10	50
BER:	5	9	45	10	50	8	40
ACCESS TIME:	7	4	28	8	56	10	70
SPECIAL:	5		0	5	25	10	50
TOTALS	100		742		709		927

TABLE 10: SHORT TERM ARCHIVE

Optical disk also lends itself for use in a permanent archive. After serving its purpose in the short term archive, the optical disk may be removed and placed into a permanent archive. The life span of the optical disk media is reported to be greater than ten years, five time the life span of magnetic tape.

Short Term Customer Data Archiving Recommendation

It is recommended that the optical disk jukebox technology that was developed for Marshall Space Flight Center and Rome Air Development Center be used for short term archiving. Optical disk provides a low cost, low risk method of archiving the data for a short term, on-line with the possibility of transferring the media to a permanent archive, thus achieving cost effectiveness. Development effort should be focused on increasing the data rate and reducing the media cost.

On-Board Space Station Data Base Mass Storage

For the purpose of this trade study, the IOC on-board space station data base management system (DBMS) will be sized to provide storage for:

30 Mbytes	Application programs
50 Mbytes	Telemetry data acquisition
10 Mbytes	Checkpoints
5 Mbytes	Engineering data
5 Mbytes	Procedures
5 Mbytes	Schedules
144 Mbytes	Growth margin
249 Mbytes	Total

The full design characteristics for the on-board DBMS mass store are:

2×10^9 bits capacity
10 Mbit/second transfer rate
40 millisecond access time
TBD BER (because of critical nature: 10^{-12} ?)
Inside space station, 28.5^o orbit for $>$ 10 years
Space flight constrained phyisicals
230 Rads/year

The device options for the on-board space station DBMS are:

1. Magnetic Disk
2. Eraseable Optical Disk
3. Magnetic Bubble Memory
4. Semiconductor (CMOS)

Other options such as read only optical disk, write-once optical disk, video tape, ect. may be used for other non-driving DBMS storage requirements applications such as entertainment and manual updates.

Magnetic Disk

Present Winchester technology characteristics match the requirements of the DBMS mass store quite nicely, thus making magnetic disk an attractive candidate. The mass store designed with projected magnetic disk capabilities would have the following characteristics:

Capacity:	3×10^9 bits
Transfer Rate:	20 Mbits/sec
BER:	$< 10^{-10}$
Rad Hardness:	Good
Volume:	600 inches^3
Weight:	50 lbs
Power:	200 watts peak
Recurring Cost:	$11,000*
Risk:	Low
Reliability:	Good/device
Maintainability:	Modular replacement
Growth Potential:	High

* Space qualification cost not included

Magnetic disk would provide more than adequate storage capacity and easily meet all but one of the design characteristics. Magnetic disks low score is in the area of bit error rate, but with improved techniques or coding schemes this will not be a problem. Space qualification of magnetic disk devises should not be a problem as there are flight qualified devices now available. Technology expandability and insertability look to be very good.

Optical Disk

A DBMS mass store designed with the same eraseable optical disk technology discribed for the space station high rate data buffer would have the following characteristics:

Capacity:	8×10^{10} bits
Transfer Rate:	100 Mbits/sec
Power:	200 Watts average
Volume:	5100 inches^3
Weight:	200 lbs
Cost*:	TBD (rough order of magnitude: $1,000,000)
Rad Hardness:	TBD (good)
Development Risk:	Medium high
Reliability:	Consistent with a device with moving parts
Maintainability:	TBD

* Price does include space qualification cost.

Because eraseable optical disk is a new technology, the development risk is much higher than that of magnetic tape, but the technology for the "Optical Disk Buffer" has been demonstrated in the lab, and with proper funding the device can be developed and ready for use in the 1992 space station.

Magnetic Bubble Memory

A DBMS mass store designed with magnetic bubble memory would have the following characteristics:

Capacity:	2×10^9 bits/system, 667 Mbits/subsystem
# of devices/subsystem:	125
Transfer Rate:	10 Mbits/sec/subsystem, 400 Kbits/sec/device
BER:	10^{-14}
Access Time:	10 milliseconds
Rad Hardness:	Poor to Good (depends on AF development effort)
Volume:	750 inches^3/system
Weight:	25 lbs/system
Power:	$>$600 watts
Recurring Cost	$12,500
Risk:	Medium (depends on AF development effort)
Reliability:	High (solid state device)
Maintainability:	Modular replacement
Growth:	High

The DBMS mass store designed using bubble memory would meet all the performance requirements. The Air Force has a development effort to produce a space qualified bubble memory.

Semiconductor; Complementary-Metal-Oxide-Semiconductor (CMOS)

CMOS was selected as the semiconductor candidate for a DBMS mass store because it has the best capacity/power, capacity/volume, and capacity/weight ratios of the semiconductor options. A mass store designed with 1 Mbit CMOS memory would have the following characteristics:

Capacity:	2×10^9 bits
# of devices used:	2000
Transfer Rate:	10 Mbits/sec
BER:	Very good
Access Time:	1 usec/device
Rad Hardness:	10^5 Rads total dose
Volume:	1000 inches^3
Weight:	100 lbs
Power:	Depends on memory system design (around 100 watts)
Recurring Cost:	$62,400
Risk:	Low
Reliability:	Very High
Maintainability:	Modular Replacement
Growth:	Low to Medium, system designed to specification.

Semiconductor is a good candidate for use as the DMS mass store because of its good performance figures, low risk, high reliability, and good physical specifications. The development cost for CMOS is low because of commercial demand for it in the marketplace. Even though CMOS is a volatile memory, non-volatility can be provided with a battery backup.

On-Board Space Station DMS Mass Store Results

After assessing the various options to see how well they would fit into the space station DBMS mass store the options were ranked from one to ten (ten being best) for each criterion. Table 11 presents the results of the ranking. Optical disk, magnetic disk, magnetic bubble memory, and CMOS semiconductor all are good candidates for the space station DMS.

CRITERIA	WEIGHT	OPTIONS: MAGNETIC DISK	TOTAL	OPTICAL DISK	TOTAL	MAGNETIC BUBBLE	TOTAL	SEMICONDUCTOR CMOS	TOTAL
COST									
DEVELOPMENT:	4	9	36	7	28	8	32	10	40
RECURRING:	5	9	45	7	35	10	50	8	40
MEDIA:	1	8	8	7	7	10	10	9	9
DEVL. RISK:	15	9	135	7	105	6	90	8	120
GROWTH									
EXTENDABLE:	7	10	70	9	63	8	56	7	49
INSERTABLE	8	10	80	9	72	8	64	7	56
RAM									
RELIABILITY:	6	7	42	8	48	10	60	9	54
AVAILABILTY:	5	8	40	9	45	7	35	10	50
MAINTAINABILITY:	4	7	28	8	32	10	40	9	36
PHYSICALS									
WEIGHT:	5	8	40	7	35	10	50	9	45
POWER:	10	9	90	8	80	7	70	10	100
ENVIRONMENT									
RAD HARDNESS:	5	8	40	8	40	7	35	8	40
SHOCK & VIB:	5	7	35	8	40	10	50	10	50
PERFORMANCE									
CAPACITY:	3	10	30	10	30	7	21	7	21
TRANSFER RATE:	3	9	27	10	30	7	21	8	24
BER:	4	8	32	7	28	10	40	9	36
ACCESS TIME:	5	7	35	8	40	9	45	10	50
SPECIAL:	5	2	10	10	50	0	0		0
TOTALS	100		823		824		777		820

TABLE 11: ON-BOARD SPACE STATION DBMS MASS STORE

The most significant discriminators between the options are:

1. Development Risk
2. Development Cost
3. Reliability
4. Power
5. BER
6. Special Considerations

Magnetic disk provides the needed characteristics in current devices. This is a major factor in it's favor because it lowers development risk and development cost. Factors against magnetic disk include: moving parts that make it more unreliable than a solid state device and a higher bit error rate than that of a solid state device.

Eraseable optical disk has very good performance characteristics. The projected characteristics will provide for growth.

Bubble memory meets most of the requirements of the space station DBMS. Bubble memory would need the most development of the three candidates for the DBMS and current efforts in bubble memory development are not adequate to make bubble a low risk option. Bubbles main advantages are in the criteria of reliability and maintainability.

CMOS semiconductor is a close second according to the figure of merit. It has good performance, high tolerance to radiation, low development cost, and low power requirements. As with magnetic disk, present CMOS devices can be used to build the DBMS mass store, thus giving CMOS a low development risk. There are no major factors against the use of CMOS as the DBMS mass store.

<u>Space Station DBMS Mass Store Recommendations</u>

It is recommended that eraseable optical disk be used for both IOC and growth space station DBMS mass store. Eraseable optical disk provides more than adequate storage capacity and transfer rate. Eraseable optical disk also lends itself to growth and modular replacement.

Magnetic Disk can also meet the design characteristic for the DBMS mass store requirement and should be used if optical disk development does not take place as recommended.

CMOS semiconductor can also meet the requirements imposed by the DBMS but does not have the growth capability of magnetic disk. Bubble memory currently has too high a development risk to be considered for the IOC space station, but with proper development funding might make a good candidate for use on the growth space station.

8. Conclusions

Eraseable optical disk, because of its high performance and small size, is the recommended option for these application areas provided sufficient technology development and demonstration can be accomplished for IOC-Regardless of the final IOC configuration this technology should be developed for the growth space station.

1. Space station high rate buffer
2. Space station PLAN communication data buffer
3. Polar-orbit platform data buffer
4. Data handling center buffer
5. Space station DBMS mass store

If the eraseable optical disk devices are developed as recommended, the perceived development risk associated with this option will lessen. This is due to the increased development funding that can be supplied while still holding down overall development cost. The recommended development approach will bring about commonality between devices and spare parts that will further reduce costs.

If development does not proceed as recommended then magnetic tape should be used for all the above application areas except the space station DBMS mass store, in which case magnetic disk should be used.

Write-once optical disk should be used for the short term archiving application. The technology is already being used at Marshall Space Flight Center and Rome Air Development Center. It is a low cost, low risk option.

XVI. COMMAND AND RESOURCE MANAGEMENT

COMMAND AND RESOURCE MANAGEMENT
TRADE STUDY REPORT

1.0 TRADE STUDY DEFINITION

1.1 Reason for Trade Study

The command and resource management capability provided by the SSDS will be used extensively by the customer to functionally interact with his payload from his own institution/facility, including both on-board and ground elements. This trade study will identify and evaluate five candidate system designs for command and resource management that represent a spectrum of attractive concepts.

1.2 Background

The SSDS allocates Command and Resource Management to two major functions: 2.0 Manage Customer/Operator Supplied Data, and 3.0 Schedule and Execute Operations. A command management and resource management system must be innovatively improvised to address a wide range of requirements. Requirements for command management include the following:

- Authenticate Command Sender and Address. (Reference 1)
- Determine Command Classification (Restricted, Constrained, or non-restricted). (Reference 1)
- Pass non-restricted commands and data directly to their destination with no further checking. (Reference 1)
- Determine whether restricted and constrained commands are executable. (Reference 1)
- Pass executable, restricted and constrained commands to their destination at appropriate times. (Reference 1)

PRECEDING PAGE BLANK NOT FILMED

- Attempt to resolve problems with not-executable commands. (Derived)

- Return not-executable commands to sender. (Reference 1)

- Allow customer to be able to cancel any command he initiated. (Derived)

- Report all command disposition and status to sender. (Reference 1)

- Provide for command data privacy. (References 1 & 2)

- Process all commands in a manner consistent with customer real time, interactive operation. (Reference 1)

- Support generation and real time change of stored command sequences. (Reference 1)

- Support customer payload commanding. (Reference 1)

- Make command entry and resolution user friendly. (Reference 1)

- Enable customer payload control to be essentially the same as if the payload were in his own laboratory. (Reference 1)

Requirements for resource management functions include the following:

- Accept and verify operations requests from customers and station operators. (Reference 1)

- Receive and confirm Major Event requirements from SSP. (Derived)

- Negotiate Communications Requirements with NCC. (Reference 1)

- Develop an optimum schedule consistent with constraints of power, crew task selection, communications bandwidth, and non-interference among payloads and Space Station systems. (References 1 & 2)

- Revise schedule in accordance with changing requirements, priorities, opportunities, and capabilities. (Reference 1)

- Hold scheduled commands and dispatch at appropriate time. (Reference 1)

- Support onboard, near term planning by the crew. (Reference 2)

- Provide customers and operators data on Space Station resources and availability. (Reference 1)

- Provide a single point of contact for customer communication reallocation requests. (Reference 1)

- Accommodate a phased degree of Space Station autonomy. (Reference 2)

- Make Resource Management user friendly. (Reference 1)

- Ensure customer payload and core system do not interfere with each other and do not endanger the health and safety of the Space Station system. (Reference 1)

Most of the above listed requirements are contained within the Customer Requirements for Standard Services (Reference 1) and/or Space Station RFP (Reference 2). Some additional requirements are included as derived from MDAC analysis.

Communication (especially real time), power,. and crew time have been identified as being the limiting resources in resource management. A comprehensive analysis is used to identify preferred system design characteristics in this area. It is desired to minimize customer requirements (outside of initiating commands) through provisions for "customer transparent" checking, scheduling, etc. That is to say, the customer is kept oblivious of operations not concerning command initiation as much as possible. These features are to be maximized while drivers such as limiting resources are accommodated when selecting an optimum system.

1.3 Candidate System Options

The five systems and their key features to be addressed by this trade study are shown in figures 1 through 5. System #1 represents full SSDS responsibility for payload functions and customer responsibility for determination of command executability. No command checking exists between the customer and payload. System #2 represents SSDS checking of all restricted/constrained commands. Single tier checking exists between the customer and payload along with support for customer interactive planning of the space station schedule. System #3 enables payloads and core systems to originate commands. It contains a single tier checking function onboard the spacecraft. The payload sends restricted and constrained commands out for approval. System #4 contains multiple tiers of restricted, constrained command checking. A separate path exists for non-restricted and executable commands. Each tier may dump a checked command to the "executable" path. Some checking may be performed by the customer prior to entering the SSDS. The payload must reject improperly checked commands. System #5 provides apriori resolution of problem commands and multiple tier checking through its integrated command checking and scheduling. Again, this system incorporates a separate path for non-restricted and executable commands. It also provides for a scheduling service at the customer's request.

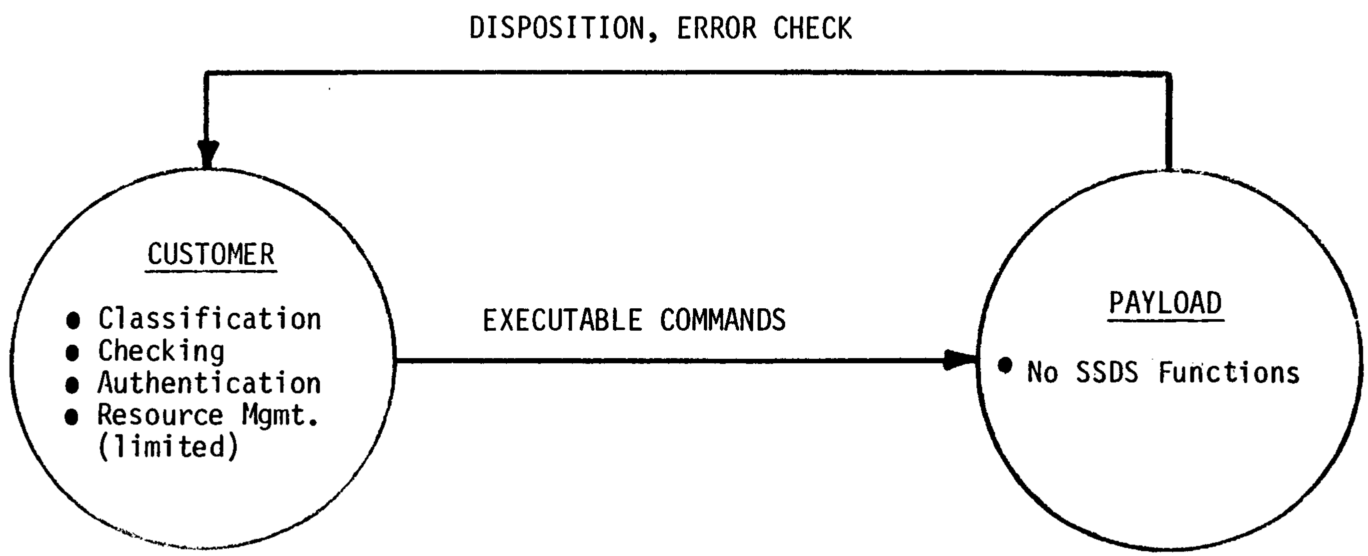
1.4 Issues

The following items represent major areas of concern relative to making value judgements on the candidate systems capability for command and resource management and are incorporated into the trade study criteria (See section 4):

a. What is the risk that present or new technology can meet development, production (producibility), and cost/scheduling requirements?

b. What level of standardization/commonality should be achieved?

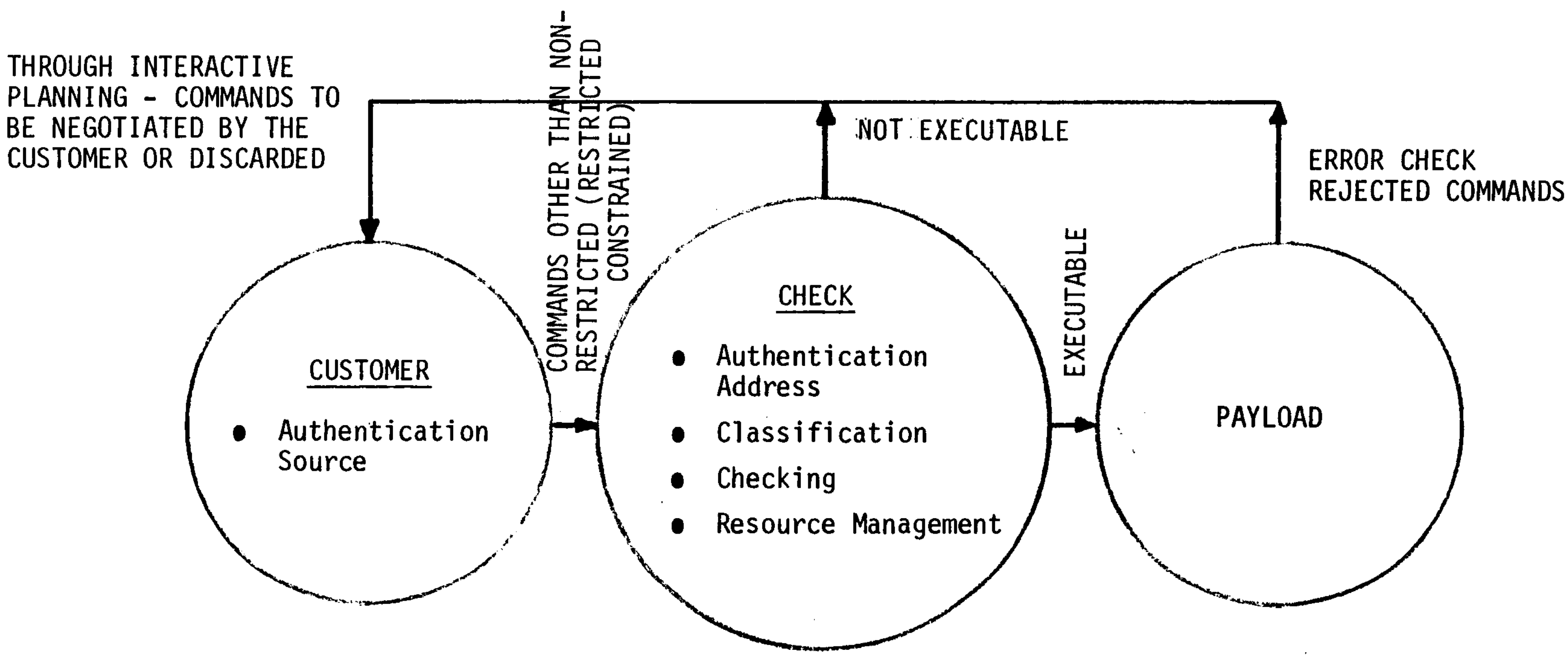
c. How much growth/technology insertion potential should be instituted?



FEATURES

- No command checking between customer and payload.
- Payload performs no logical SSDS functions.
- Minimal opportunity for Resource Planning.

Figure 1. System #1 - Customer Responsible for Determining Command Executability



FEATURES

- Non-restricted commands are checked for address, only, then sent directly to the payload.
- Commands other than non-restricted commands are checked by SSDS (Authentication of Address; Classification, Resource Management).
- Payload performs no SSDS functions.
- Single tier checking.
- Payload must reject erroneous commands.
- Supports customer interactive planning of the space station schedule.

Figure 2. System #2 - SSDS Checks All Commands.

FEATURES

- All commands flow directly from the customer to the payload.
- Checking and resource management onboard.
- Check can command core systems.
- Payloads and core systems can originate commands.
- Full duplex error check on uplink commands.
- Single tier checking.

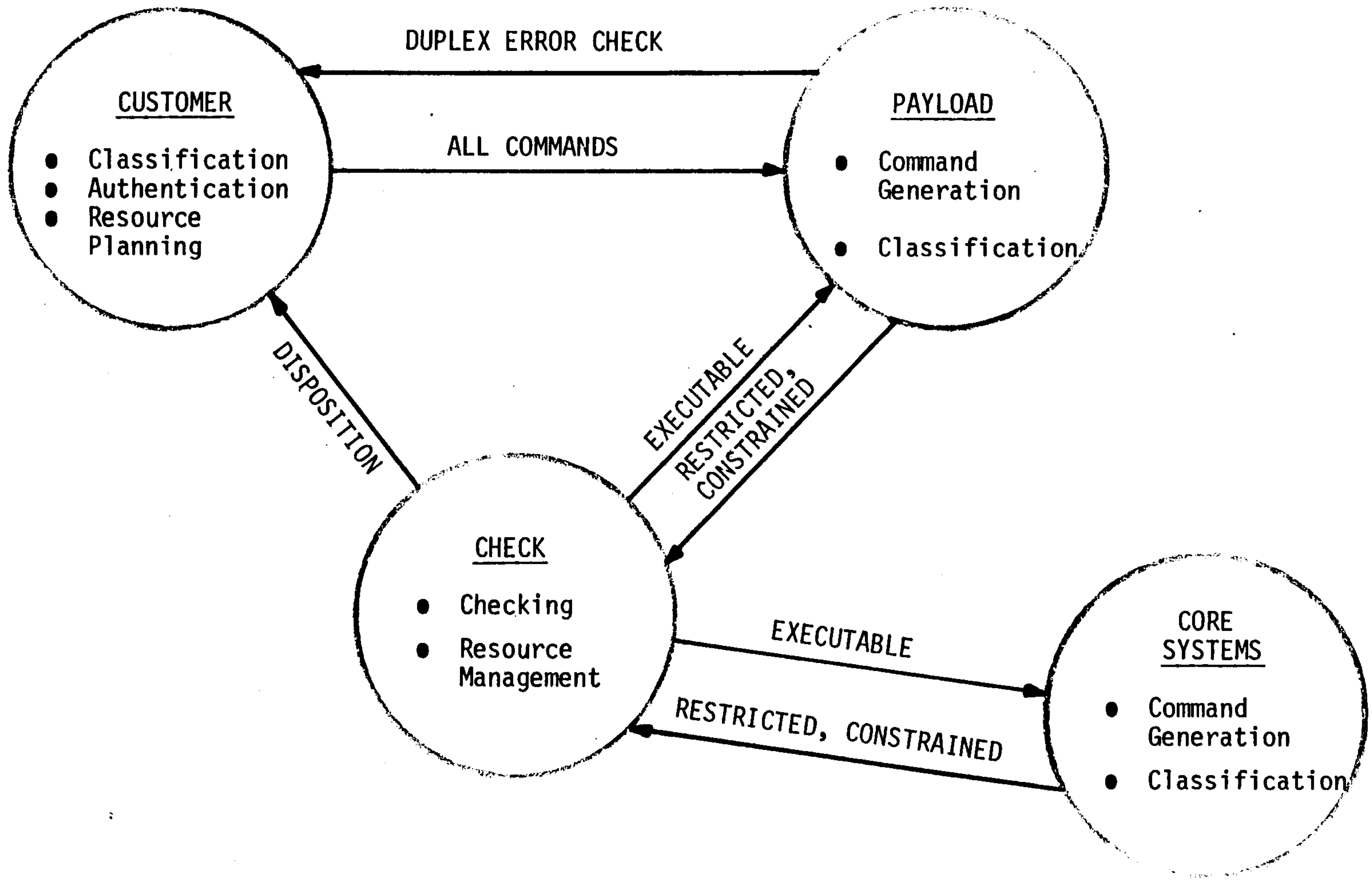
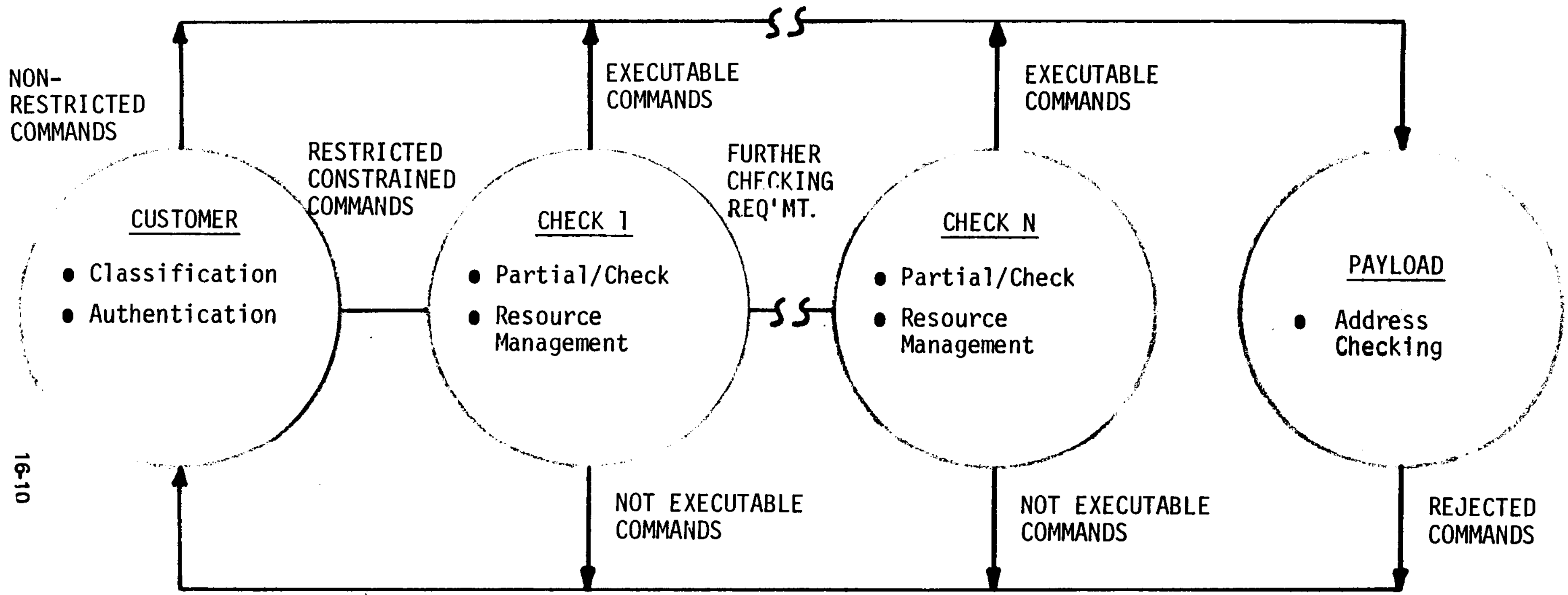


FIGURE 3. System #3 - Payload Sends Restricted, Constrained Commands Out For Approval

C-4

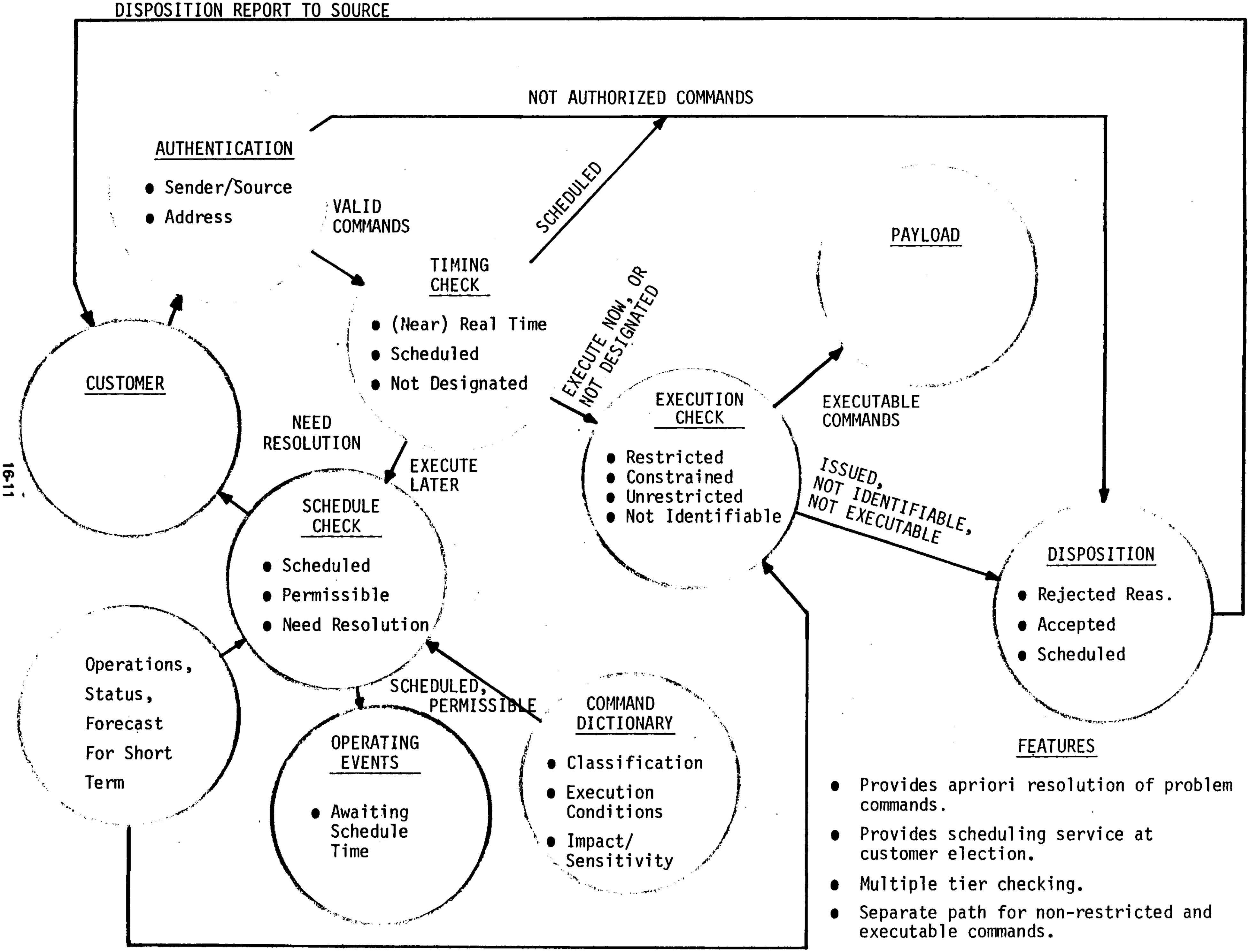


FEATURES

- Separate path for non-restricted and executable commands.
- Multiple tier checking. Partially inside, partially outside SSDS.
- Payload must reject improperly checked commands.

Figure 4. System #4 - Multiple Tiers of Restricted, Constrained Command Checking

FIGURE 5. System #5 - Integrated Command Checking and Scheduling



FEATURES

- Provides apriori resolution of problem commands.
- Provides scheduling service at customer election.
- Multiple tier checking.
- Separate path for non-restricted and executable commands.

d. What level of performance in the areas of reliability, maintainability and responsiveness is needed to be attained?

e. What will be the cost effectivity in the development (nonrecurring), unit (recurring) and life cycle (training, maintenance and operation) operations?

f. Which resource drivers will be most significant in determining the optimum system trade offs?

g. What factors are to be included for a realistic sensitivity analysis of all candidate systems?

h. Which systems carry more weight from a customer accommodation perspective?

i. What is the most cost-effective integration scheme that will satisfy performance requirements, buildup sequence, scheduling, and checking of application functions?

1.5 Trade Study Criteria

The Command and Resource Management systems will be evaluated in two separate steps. The first step addresses the degree to which the system meets requirements. The applicable requirements and their sources are:

A. Does the customer receive assurance of error free delivery of his command to his payload?

B. Does the customer know whether a command is delivered? (Reference 1: 1.1.8).

C. Can the customer cancel any command he initiated?

D. Is resolution performed on not executable commands (e.g., develop time slip requirements to enable a formerly not executable command to become executable) (Reference 1: 6.1.6.2).

E. Does the customer receive reasons for not executable commands? (Reference 1: 7.3.4.1).

F. Are all not executable commands negotiable by the customer?

G. Are all not executable commands returned to the customer? (Reference 1: 6.1.3.1)

H. Is the customer (sender of commands) and address authenticated? (Reference 1: 1.1.4 & 6.1.4).

I. Can classification be determined on all commands (e.g., restricted, constrained, or non-restricted)? (Reference 1: 6.1.6 & 7.2.5).

J. Is there assurance that all commands will be properly classified?

K. Are non-restricted commands passed through the SSDS without any further checks imposed on them? (Reference 1: 6.1.6.3).

L. Can a customer functionally interact with his payload in the same manner as if the payload were in his laboratory and enable him to conduct his experiment(s) from his own institution/facility (Reference 1: 6.1.3).

M. Does SSIS provide adequate servicing of command processing so that the customer requirements is minimized within the command management system framework? (Reference 1: 1.1.4, 1.1.8, 6.2.1)

N. Can command privacy be maintained at all times? (Reference 1: 2.2.2).

O. Is there adequate security against disclosure of command information to unauthorized personnel? (Reference 1: O-3).

P. Are restricted and constrained commands logically separated from the general uplink? (Reference 1: 7.3.4.1).

Q. Does the system support customer interactive planning of the Space Station schedule? (Reference 1: 7.2.1 & 7.2.2.1).

R. Is customer allowed to enter his commands in bulk? (Reference 3).

S. Is real-time interaction available? (Reference 1: 6.2.1, 6.2.1.2 & 6.2.1.3).

The second step addresses the following qualitative evaluation criteria:

Cost – What relative cost level is associated with the buildup, operation and future growth of the system?

Schedule – What is the probability for successful implementation of the system within the available seven year total program schedule?

Performance – Is the level of performance satisfactory? Performance includes real time command (no substantial increase in response time over that necessary for communications – estimated to be approximately one second) and the ability of a system to handle throughput.

Resource Effectiveness – Are spacecraft resources used efficiently, i.e, to what degree can a system facilitate resource management?

Customer Accommodation – Can the customer be accommodated effectively, i.e., to what extent can a given system maximize the value of customer payload product?

FMEA – What failure mode effects exist, i.e., what is the relative potential for catastrophic failure modes for a given system?

Resource Availability - Is there a suitable availability of resources including considerations such as the location of required resources, criticality of required resources, and the type of required resources?

Flexibility - Does the system have adequate flexibility to handle future growth and technology upgrade?

2.0 Methodology

The basic approach which will be utilized for the trade study on candidate command and resource management systems consists of the following:

- o Fully describe the systems to be traded showing their intrinsic features.
- o Modify systems to fully meet all application requirements if possible without altering each system's basic essence.
- o Evaluate the candidate systems relative to qualitative evaluation criteria specifically designed for the command and resource management trade study.
- o In the future, a computer simulation model should be developed to facilitate the sensitivity analysis. This would greatly enhance a capability to gain further insight into all possible acceptable combinations with regard to the practical operation.

3.0 Results

As indicated in Section 1.4, the trade study was conducted in two steps.

The requirements evaluation is shown in Table 1. The ratings against requirements are: Yes, No, Partially, and Maybe, indicated by Y, N, P, and ?. Systems #4 and #5 are shown to successfully meet all criteria. Systems #2 and #3 will require some modification so that all criteria can be met. System #1 will not be able to meet all the criteria without substantial modifications. Note that modification required for systems #1, 2, and 3 would change these systems intrinsically.

The evaluation of the systems against the qualitative evaluation criteria is shown in Table 2. The ratings made were as follows: High, Low, and Medium, indicated by H, L, and M. Systems #4 and #5 appear to handle most of the criteria the best. With limited modification these two systems would be able to score well with respect to all criteria. Systems #1, #2 and #3 would

Table 1
System Evaluation Against Requirements

Requirement	System #1				System #2				System #3				System #4				System #5			
	Y	N	P	?	Y	N	P	?	Y	N	P	?	Y	N	P	?	Y	N	P	?
A	X				X				X				X				X			
B	X				X				X				X				X			
C	X				X				X				X				X			
D		X			X					X			X				X			
E		X			X				X				X				X			
F		X					X		X				X				X			
G		X			X				X				X				X			
H	X				X				X				X				X			
I	X				X				X				X				X			
J		X			X					X			X				X			
K	X					X			X				X				X			
L		X					X		X				X				X			
M		X				X			X				X				X			
N	X				X				X				X				X			
O	X				X				X				X				X			
P		X				X				X			X				X			
Q		X				X			X				X				X			
R	X				X				X				X				X			
S	X				X				X				X				X			

Table 2
Qualitative System Evaluation

Evaluation Criteria	System #1			System #2			System #3			System #4			System #5		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
COST			X			X	X			X			X		
SCHEDULE (7 year prob- ability)			X			X	X			X			X		
PERFORMANCE -Real time Command* -Ability to Handle Through put	X				X			X			X				X
RESOURCES (Can facilitate resource man- agreement)			X		X			X			X		X		
CUSTOMER ACCOMMODA- TION***			X		X			X		X			X		
POTENTIAL FOR CATAS- TROPHIC FAILURE MODE			X		X			X		X			X		
SYSTEM** AVAILABILITY OF RESOURCES			X		X			X		X			X		
GROWTH/ TECHNOLOGY UPGRADE			X		X			X			X		X		
Overall Ratings			X		X			X		X			X		

* No substantial increase in response time over that necessary for communication: + 1/2 second.

** Location, criticality and type of resources are considerations.

*** Maximize value of customer payload product.

require extensive modification to score well against the qualitative criteria. This would mean these three systems require alteration from their basic intrinsic features.

Systems 4 and 5 appear to be intrinsically adequate in satisfying the requirements and qualitative evaluation criteria. Systems 1, 2 and 3 fail in totally satisfying all of the requirements and qualitative evaluation criteria based on their individual intrinsic features. Therefore, they are not acceptable as designed.

4.0 Conclusions, Recommendations and Issues

A. Further trade study effort should be performed on systems 4 and 5 through a sensitivity analysis.

B. Systems 1, 2 and 3 need not be explored further unless modifications to alter their basic intrinsic features is decided upon as being acceptable.

5.0 REFERENCES

1. "Customer Requirements for Standard Services from the Space Station information system (SSIS)" NASA JSC Level B, Revision 2 dated March 1, 1985.

2. "Space Station Definition and Preliminary Design" NASA JSC RFP G-BF-10-4-01P, September 15, 1984

3. "Space Station Mission: Requirements." Space Station Task Force Mission Requirement Working Group (MRWG) and NASA LaRC computerized data base, May 1984.

SPACE COMMUNICATIONS

1.0 Introduction

End to end communications service for any user information precesses across a number of communications links as well as undergoing processing at a number of nodes during the flow towards the "sink". The end to end aspect includes on board (POP/COP/SS) connectivity, the link to (and from) the ground, the NASA distribution network (NASCOM, land satellite service, local links), as well as level "O" processing for format/error protection/routing/queue service, signal processing, and also the linkage of engineering support information (event, time, environmental conditions and/or settings, etc) to the actual payload data.

The information itself may also suggest different modes of handling, i.e. some may require precedence handling (e.g., emergency events), some may be constrained to real time delivery as opposed to delayed delivery; some may require a high degree of error protection while other information (e.g., video) may be sufficiently robust that error handling doctrine may be minimal.

The growth patterns which are anticipated as the SSIS matures, (see Task 4, SSDS report), must be accommodated by the communications system in a relatively straightforward manner. Therefore, there must be a level of flexibility and adaptivity (near real time and also as events are scheduled) built into the basic architecture. In addition, the Space Station will generate video and audio information which will require distribution both on-board and to ground facilities (users, POCC's, public affairs, etc). This information, in conjunction with core data and payload data, are the components of the communications portion of SSIS. Command and control, video and audio, and program uploads are the primary contributory components of the "forward" link to the Space Station. The COP and POP communications needs are dominated by experiment data, however, command and control are also required for the uplinks to these platforms.

Finally, processing at various locations in the end to end chain, if not adequately addressed, can cause delivery delays, create multiple levels of processing which affects S/W (and H/W) cost and development uncertainty, and perhaps create an institutional rigidity which will be difficult to change as the Space Station program evolves. It should be an objective that processing points in the end to end chain, be located where ground level processing can be most efficient. Level "0" and "1A" processing is discussed in Task 4 Section 7.0 (Ground SSDS definition).

This section concentrates on space communications, identifies various high level options for efficient use and implementation of the space to ground links, and via comparative tradeoff identifies the most attractive options.

2.0 Ground-Space Architecture

In order to support the maturing of the Space Station program and the likely changes in emphasis, mission experiments, and the presence of payloads on the COP and POP platforms, as well as the Space Station, the TDRSS return (down) link is addressed here as the primary link to ground. The discussion below considers the Ku band (single access link) as the primary down trunk because of its 300 MBPS capacity; the availability of S band links (single and multiple access) are implied but except for information partitions and therefore processing simplification, these add minimal capacity to the required band width.

The primary emphasis below is on the use of TDRSS, TDRSS enhancements, or augmentation to the down link to accommodate special loading or service demands.

2.1 Ground to Space Architecture Options

The following list of options have been identified:

a. 1,2,3,4 satellite TDRSS configurations.
b. TDRSS augmented by enhancements or TDAS.

c. TDRSS augmented by a commercial satellite utilizing a combination of TDRSS and ACTS technology.

d. TDRSS augmented by direct downlink to the DSN.

e. All users required to provide for their requirements in excess of TDRSS capacity.

The capacity characteristics of the TDRSS links are shown in Table 1.

TABLE 1 – TDRSS DATA RATE CAPACITIES

SERVICES AND PARAMETERS	MA	SSA	KSA
FORWARD LINK SERVICES			
QUANTITY OF LINKS PER TDRS	1	2	2
TOTAL LINKS FOR THE TDRSS	1	4	4
RETURN LINK SERVICES			
QUANTITY OF LINKS PER TDRS	20	2	2
TOTAL LINKS FOR THE TDRSS	20	4	4
FORWARD LINK			
MAXIMUM USER DATA RATE	10 KBPS	300 KBPS	25 MBPS
RETURN LINK			
MAXIMUM USER DATA RATE	50 KBPS	3 MBPS	300 MBPS

	PER TDRS	TOTAL FOR TDRSS
TRACKING LINKS		
ONE-WAY DOPPLER	10	10
TWO-WAY RANGE AND DOPPLER (MA)	1	2
TWO-WAY RANGE AND DOPPLER (SA)	4	6

NOTE: THIS TABLE IS BASED ON 2 SATELLITES DEDICATED TO TDRSS SERVICE; SOURCE: SPACE NETWORK TDRSS DATA BOOK, APRIL '85.

2.1.1 Four Satellite (TDRS) Configuration

TDRSS utilization in 1,2,3, or 4 satellite configurations requires examination of the impact of Zone of Exclusion (ZOE), hardware impact and operations effect. Table 2, based on projected locations for these various TDRSS options, summarizes these considerations. In summary, the ZOE means that any data collected during this period cannot be "sent down", thus suggesting two general strategies. The first is to continue to collect such data, buffer until TDRSS returns to view, and then transmit. This means, for example (using the 15% exclusion zone) that the down link must handle, in the worst case, 1.15 (the normal) data rate. This leaves unresolved such questions as to whether a First In-First Out (FIFO) protocol is to be followed once TDRSS accessibility is restored, or whether a level of source data throttling should be introduced during ZOE. These are issues which can best be addressed by mission oriented tradeoffs.

Another issue is the fact that multiple TDRSS "birds" suggest the use of at least two TDRSS antennas on the user platform so that maximum use can be made of the available channels. In this case, the handover process becomes a factor, probably requiring covering signals from two (or more) TDRSS platforms (using the forward link for establishing a reference). Signal acquisition and re-acquisition (how long? how to point?, how to know which antenna/TDRSS is in view?) are the implementation considerations.

Finally, one general factor in the architectural equation is the desire to time share (COP, POP, and Space Station) the linked TDRSS resources; event and access scheduling are essential to service all three platform types.

The TDRSS capacity is listed in Table 1; the major downlink (Ku, SA) is rated at 300 MBPS. One of the major factors in the data rate is the modulation scheme (QPSK). By the use of a different modulation method (eg. 8-ary), the data rate can be substantially increased.

A 50-100% increase (depending on whether the channel is encoded or not) is theoretically possible; the technology is reasonably well known.

TABLE 2 - TDRSS OPTIONS VS ZOE

# TDRSS SATELLITES	APPROX. LOCATION	ZOE % OUTAGE	CHARACTERISTICS
1	41 W	APPROX. (40-50)%	A) Large data buffers and/or throttling during ZOE; B) Re-acquisition required
2	41 W 171 W	15%	A) Throttle back/buffer data during ZOE B) Have East-West handover problem: C) One - SS antenna requires fast slow rate and fast acquisition Two - SS antennas minimize data loss during handover.
3	41 W 61 W 171 W	15%	A) Increased data capacity 50% of orbit B) Complex antenna handover procedures (could run at 300 MBPS 85% of time through 1 & 2, using third TDRSS to dump ZOE data also at 300 MBPS).
4	41 W (2) 171 W (2)	15%	Doubled information capacity 85% of orbit; East-West handover problems; changes at ground terminals antenna system.

Basic Source: TDRSS User Guide

2.1.2 TDAS Augmentation of TDRSS

The TDAS satellite, which is now in the planning phase could be available in the early phases of the Space station program (e.g., 1995-2000). A comparison with TDRSS is shown in Table 3. It is obvious that it offers substantially more capacity than TDRSS (approx. 1 GBPS vs 300 MBPS for the single access return (down) link) and projects the use of steerable regional or spot beam antenna which could reduce the terrestrial network load by directing data to regional locations.

TABLE 3 – TDRSS vs TDAS CAPABILITY SUMMARY
(SOURCE: TDAS FOR THE 1990's; 5/31/83)
STI REPORT TO GODDARD

	TDRSS	TDAS
MULTIPLE ACCESS	• 1 FORWARD CHANNEL • 20 RETURN CHANNELS (SYSTEM MAX) • BEAMFORMING AT GROUND	• 2 FORWARD CHANNELS • 10 RETURN CHANNELS PER S/C – LINK GAIN INCREASES BY 4.5 dB • ONBOARD BEAMFORMING
SINGLE ACCESS	• 2 K–(OR S–)BAND PER S/C • DATA RATES TO 300 Mbps	• K–(OR S–) BAND • 5 W–BAND PER S/C • 1 LASER • DATA RATES TO 1 Gbps
SPACE–TO–GROUND	• SINGLE BEAM ANTENNA – 1 FIXED LINK • Ku BAND TO WHITE SANDS • DOMSAT RELAY	• MULTIPLE BEAM ANTENNA (5 FIXED HORNS, 4 STEERABLE) – 5 FIXED LINKS – 1 MOBILE LINK • ONBOARD TWO–WAY SWITCH • RETAIN Ku AT WHITE SANDS, USE Ka AT ALL OTHER SITES • NO DOMSAT RELAY
CROSSLINK	• NONE	• 1 FORWARD PER S/C (25 Mbps) • 1 RETURN PER S/C (1.8 (Gbps) • LASER OR 60 GHz

The problems are technical uncertainty and programmatic (will it be funded and when will it be available). Network management complexity will also be a factor in addressing operational level decisions.

2.1.3 COMSAT/ACTS Augmentation of TDRSS

TDRSS augmented by a commercial communications satellite capability on the Space station (or the POP or COP), where that satellite could use the multiple access and antenna pointing technology of the Advanced Communications Technology Satellite (ACTS) Program, could offer an increase in down link capacity and allow for connection to regional or user facilities. ACTS technology is being developed under NASA contract, and is to be tested in the 1988-1990 time frame. A potential application of ACTS technology is to support the distribution of TDRSS return link data from White Sands to regional user sites.

2.1.4 Direct Downlink To DSN

Augmenting TDRSS by links to a network such as the Deep Space Network is possible for off loading the TDRSS. DSN is not a high capacity network, but could be used for additional coverage for moderate data demands. However, at best it might be used for emergency down links, rather than as an integral part of the SSIS communications structure.

2.1.5 User Provided Downlink

Customers might want to or be required to provide for direct down links from the Space Station (or COP or POP) rather than depend on the SSDS/SSIS constraints. This alternative would affect the platform communications requirements and also offset other auxilliary areas such as power budget, electro-magnetic interference patterns, antenna and structural factors.

2.2 Conclusion

The changing traffic profile of the projected experiments makes the future a little unclear. However, the projected satellite TDRSS configuration (essentially two each stationed at East and West stations) would probably be adequate for the IOC plus some reasonable growth. This is a relatively low technical risk solution, with the caveat that the ground terminal and network would have to be modified to support both the traffic increases and the antenna footprints. Careful scheduling to avoid conflict between POP, COP, and Space Station is essential to take advantage of this robust TDRSS downlink capability.

If real time delivery delays cannot be met by this approach, then the addition of antenna steering (as in TDAS and/or ACTS technology) to delivery to regionally located data handling centers, must be considered.

3.0 DOWNLINK TRANSMISSION OPTIONS

The discussions below describe options, some tradeoff criteria, and finally the advantages and disadvantages of each, as related to the link organization. The primary criteria although implicit, is in the ability to accommodate changing requirements over the mission life and on a near real time basis to accommodate special conditions. The discussion below also assumes that audio and video information will be digitized, and that data using the return (downlink) TDRSS links will probably fit into three categories. The first is facilities/housekeeping telemetry data, which requires modest capacity (e.g., 5MBPS or less). The second is continuous and relatively high rates (e.g., 10-50 MBPS payload data); and, the third is payload data reflecting more modest requirements (e.g. 100 KBPS to 5 MBPS).

The question of packets for all data or a combination of packets with implications of 5-10% overhead (e.g. using a modified CCSDS format) and virtual/direct connection is considered. Packets impose a processing load (and associated delay); virtual connections require an adequate quality channel (within SSIS), and dynamic allocation of virtual channels to minimize scheduling and control of the experimental payload activity.

Packetization requires that onboard processing <u>and</u> the counterpart location in the ground network have responsibility for keeping the discipline of the packetized data; a virtual connection assumes that the end addressee will collect and process the data - i.e. the POCC/PI or data handling center, and requires minimal overhead in the SSIS information flow. However, the virtual connection implies no error control in the path between source and sink. The options below address these possibilities.

3.1 Tradeoff Considerations

The trade study options presented in the discussion on uplinks and downlinks, must be evaluated keeping in mind the particular characteristics of the transmitted data. Each option must not only provide for current data rates but must be evaluated as to their ability to handle increased data rates as the SSIS grows. In addition to planned events, the data transmission formats should be flexible enough to handle various emergency or contingency situations as they arise. With SSIS channel bandwidths at a premium, efficient channel utilization is an important consideration when evaluating the various options. Other factors such as routing complexity, data overhead, and the ability to redistribute data loads must also be considered. Finally, the availability of technology to support the various options must be considered; in particular, new technology presents risk for the implementer and, implicit, is the impact of uncertain costs for new technologies.

3.1.1 TIME MULTIPLEX SCHEMES

a. DEDICATED TIME SLOTS (FIXED FRAME)

This scheme is characterized by the fixed boundary within each frame which separates the low rate data packets from the high rate data stream (virtual connection), see Figure 4.1. Each frame has the same ratio of low rate data to high rate data. The scheme is tailored to the data characteristics and allows simple handling procedures since there are well defined data

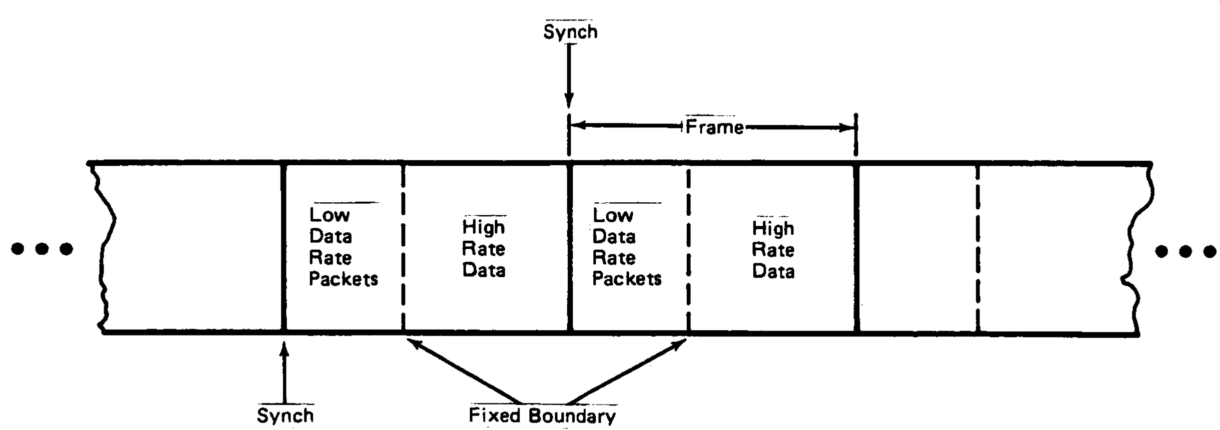


Figure 4-1. Time Multiplex Schemes — Fixed Frame

boundaries. The fixed boundaries within each frame however, do present the difficulty with channel capacity utilization,and provides limited flexibility for contingencies and growth.

Frame synchronization is very important, so that a small overhead exists to determine and acquire synch, at the start of each frame.

b. DYNAMIC ALLOCATION

This scheme is similar to the previous scheme in that each frame contains a boundary between the high rate data stream and the low rate data packets. The difference is that the position of the boundary from frame to frame is dynamically allocated according to the scheduled data rate requirements, see Figure 4.2. The scheme requires a coordination packet at the beginning of each frame to identify where the boundary is located. The coordination/signalling packet notifies the ground entry node when a change in the dynamic boundary is to occur; thus it requires a coordinating hand shake, which takes a minimum of time equal to round trip delay plus processing. The scheme provides efficient use of channel capacity and there is inherent flexibility for contingencies and growth. As a result of the dynamically changing data boundary however, relatively complex data handling procedures are required.

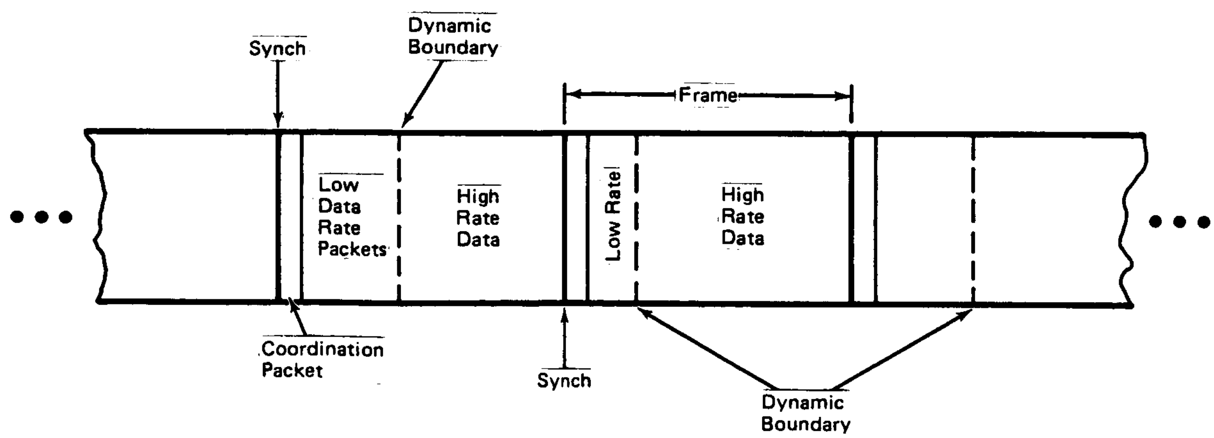


Figure 4-2. Time Multiplex Schemes — Dynamic Allocation

c. TOTALLY PACKETIZED

In this scheme both the low rate data and high rate data are packetized and then multiplexed into the frames. As a result the scheme allows the use of standard protocols and formats. A significant overhead is required with this scheme in order to identify the contents and destination of each data packet. Discussions of various packet candidates are made in the Task 3, Section IV, Communication Standardization Trade Study, but in general the use of a standard packet (e.g. CCSDS) would simplify network transversal and intermediate processing. It is not apparent at this point, that low rate payload data and high data rate, continuous data should be enveloped into the same packet format. Thus, in the latter case, the overhead penalty would be more closely in balance with the amount of data; in the former case, processing complexity is less than with a non-standard packet format and structure.

3.1.2 Channel Allocation Scheme #1

The downlink capabilities in this scheme have been divided into three links. The first is the S-band link which will be reserved for core data. The Ku-band, I channel (150 Mbps) will be used for the second link and will be reserved for high rate or bulk data. The third link will be the Ku-band, Q channel (150 Mbps), and will be reserved for additional experimental data and/or video. As a result of the well defined data boundaries the scheme allows for simple data handling procedures. The disadvantages of this scheme include possible poor channel capacity utilization and poor flexibility for change contingency and growth.

3.1.3 Channel Allocation Scheme #2

Downlink data in this scheme will be divided between two channels. The first channel will be the S-band link and will be reserved only for core data. The Ku-band link will be the second link and will be dynamically allocated. This scheme conbines well defined data boundaries and reasonable channel capacity utilization. There is an inherent flexibility for contingencies and growth and data handling procedures are only moderately complex.

3.1.4 Channel Allocation Scheme #3

This scheme utilizes the Ku-band link for all data transmission with the S-band link reserved to smooth peak loads. As a result of dynamic allocation there is inherent flexibility and good channel capacity utilization. The primary disadvantage to this scheme is that the data handling procedures become quite complex.

3.2 Conclusions

1. Amongst the three possibilities discussed under Time Multiplexed options, the dynamic allocation is the most flexible and gives a relatively efficient channel usage mode. The dedicated time slot approach is somewhat inflexible and a major overhead penalty is required to support a fully packetized channel. Therefore, option b (Dynamic Allocation) is recommended at this time. The method of coordination between the Space Station commmunications subsystem and the ground terminal will have to be analyzed to determine complexity and capability required at the ground entry terminal.

2. It is premature to determine how to partition the downlinked (return) traffic which will use TDRSS. If throttling during excessive traffic periods is acceptable, then allocation method #3 is not necessary. However, more operational/mission user liaison is required to make any specific recommendation at this point.

4.0 UPLINK TRANSMISSION OPTIONS

The uplink to the spacecraft, could be considered in a number of categories: Space Station – uplink to include command data, uplinked event information data, program uploads data, and voice and video information; Co-orbiting Platform (COP) – If it is connected directly to ground via TDRSS, then the uplinks are for data only; if Space Station acts as a relay to the COP for uplinking, then the Space Station will be responsible for "parsing" the information stream and relaying the data to the COP; Polar Orbiting Platform (POP) – direct uplink through TDRSS for command, data and program uploads.

It is assumed that a packet format will be used for commands and program uploads data; audio and video should not require that format.

4.1 Channel Allocation Scheme #1

This scheme utilizes the S-band uplink for all core commands and utilizes the Ku-band uplink for user commands and video. The scheme possesses well defined data boundaries and inherent flexibility for contingencies and growth. The data handling procedures are only moderately complex.

4.2 Channel Allocation Scheme #2

This scheme employs the Ku-band link for all uplink information with the S-band link reserved for overflow at peak times. There is great flexibility with this scheme and good channel capacity utilization. With all data multiplexed on one channel complex data handling procedures are required.

4.3 Conclusion

Channel Allocation Scheme #1 is the lower risk approach. The partitioning of the uplink into Ku-Band and a clearly defined user group and the S-Band for a clearly defined user (core station commands) makes for a clear organization. The only concern would be to examine the user command requirements, based on the changing user data base, and determine whether there might be conflict with the uplink video requirements. Judicious scheduling could eliminate that concern.

5.0 INTERNAL (PLATFORM) ARCHITECTURE OPTIONS

It is recognized that the Onboard Local Area Networking Trade Study, Task 3, Section V, also addresses architecture options, however this section addresses only partitioning concepts of the three classes of information (data, voice and video) from a communications perspective.

The major components of the information which traverses the SSIS are data, video and audio. The on-platform communications is also composed of those elements, although, in the use of the Space Station, part of this information does not go to ground but is used to support on board and corollary space operations.

Three options exist; a distribution system (switched or bus/ring which does not partition between the three classes of information, a system which is partitioned so that each class traverses its own path, and finally a hybrid where perhaps video and audio are on one distribution system while data is distributed via a data bus (quasi-LAN) throughout the craft and to video interfaces.

Examining these options it is necessary to characterize the information traffic. Video if digitized, will require major bandwidth allocation - thus a standard broadcast quality, color, TV picture will require approximately 80 MBPS. Through various compression techniques, a highly acceptable picture can be achieved at approximately 22 MBPS. A similar condition exists for audio/speech - i.e. a straightforward (PCM) digitization technique yielding "toll" quality speech requires about 64 KBPs but the use of a different algorithm (CVSD) affords good, understandable quality of 16/32 KBPS. Although other voice digitization techniques (e.g. OPC) offer reasonable quality at somewhat lower rates, the 16/32 KBPS rate represents an easily achievable design, the 32 KBPS is used on STS, and voice loading is not a major contributer to the SSIS loading. Further, video and voice are rather robust - i.e. there is sufficient redundancy so that random errors will have little or no effect on intelligibility, resolution, etc. In addition, they are continuous (not bursty) sources.

The data tends to fit into three categories: core or facility data tends to be relatively low rate - e.g. sensors typically have rates between 10 bps and 5 KBPS. In addition, the information in this area will probably continue throughout the life of the space craft and its appearance will be highly predictable (e.g. once/minute, once/hour, etc.). Payload data tends to fit into two categories: relatively continuous, high rate, data such as would be derived from mappers and relatively modest rate sources such as materials processing.

Further, an assumption is made that data will require protection - i.e. error detection/correction coding; video and audio do not require that protection.

5.1 Bus Network vs Switched Distribution Structures

Although a switched structure is feasible it does have certain disadvantages which mitigate against it, at this stage of the SSIS development. First, it tends to be a centralized function and even though redundancy techniques are possible, this becomes a point of concern in terms of single point failure. Second, recognizing that the SSIS/SSDS will evolve as missions change and perhaps module changeover is required for the Space Station, a switched structure is more difficult to rewire and to reconfigure in a large sense.

A bus or distributed LAN, if properly designed, allows for adding or deleting terminals, payload sources, processing elements (such as data base units, memory elements) and also is more flexible as space assembly of a Space Station is considered. Further, by using by-pass techniques or even a network of smaller networks, single point failure is not a serious factor.

5.2 Bus/Network Options

The audio/video distribution can either be digital or analog on the Space Station; it is assumed that when that information merges with SSDS data on an external RF link that the information will be digitized.

If all information on the Space Station were digitally transmitted on the craft, even with compression techniques, the rates (based on traffic projections) would be well in excess of 100 MBPS, (depending on scheduled events, could be 200 MBPS) which taxes the state of the bus technologies available - even that of fiber optics. Although it is anticipated that the technology will advance over the next five years, a conservative approach is to assume separate data and audio/video distribution networks. It is also assumed that an analog distribution system, on board, using CCTV or broad band/FDM techniques, is low risk and modest cost, and could be acceptable for TV and audio interconnect service.

The primary concern at this juncture is that of the format of the on board data networks. Three generalized options appear and are listed below:

a) All data transmitted on parallel on board SSDS busses utilizing a packetized format.

b) Parallel data buses with different characteristics.

- Core data bus utilizing a packetized format for low rate transmission.
- User data bus using virtual connections for high rate/bulk data transmission.
- Direct memory access data bus for bulk transfer of stored data or bulk uploads.

c) Another option would combine data, voice, video, in a digital format on the same bus structure; however, the very high rates which would be required would require some major technology improvements.

In the first option, the packetized format might be different than that used on an RF link, because the internal network connection performance is much more predictable.

The use of a standard format has the advantage of simplifying processing. However, the use of a single network structure for all SSDS information might cause problems where high volume, continuous users gain access, denying access to lower rate users. To avoid this, either timeout or precedence is required and this complicates the processing. Further, there is a significant overhead imposed on all users (i.e. everyone uses packets).

In the second option, the core data bus would allow SSDS information to be transferred internally and to/from RF interfaces in a relatively timely and predictable manner. The "user data" bus would be set up for a specific experiment or group of experiments and would not impose a packet type overhead penalty on this data stream. This "virtual connection" has the value of being relatively efficient, but does require set up for the experiments which would fit into this category. The other element of this option is that bulk transfer could use a direct memory access into assigned buffers or memory fields. This removes a potential heavy traffic load from the internal, common users SSDS structure, and obviously is a high speed/low connect time service.

Of the two primary options, b (above) is the most attractive for the following reasons:

- The internal distribution system is most closely tailored to the characteristics of the users. Thus, by segregating by user groups, it is relatively efficient.

- It does not impose the risk that high volume data users will either be limited in the time that they may occupy the channels, or that there is a substantial packet processing penalty to be paid by the high volume users (where the stream would have to be broken into packet sizes regardless of the data characteristics).

- It affords adequate service for low speed/low rate users, payloads, and sensor telemetry information.

- The ability to accommodate major changes in payload requirements is only limited by the implemented bandwidth.

- Low priority users are not "locked out".

5.3 Conclusions

Option c), where voice, video, and data appear on the same bus is not very practical from two viewpoints:

1. Digital video is exceedingly bandwidth consuming and would require a major improvement in the technology.

2. Traffic generated by different uses exhibits characteristics (distribution, occupancy, etc.) which are very different.

Option a) and b) address a distribution structure where video and voice are either on separate (or perhaps) on a common distribution system.

Option a) combines all data on one bus structure; this means that low priority users or short duration data needs might not get adequate service if long duration users (e.g., heavy use users) occupy the bus.

Option b) partitions these data groups and thus allows for a design which is closer to these user needs by class of needs, discussed at the end of the last paragraph, above. Therefore, option b) is the presently recommended system.