

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.



FEDERAL SYSTEMS DIVISION, CAPE KENNEDY FACILITY, FLORIDA

ORBITAL/GROUND CHECKOUT STUDY
FINAL TECHNICAL REPORT

NOVEMBER 1969



FACILITY FORM 602

N70-17356 (ACCESSION NUMBER)	(THRU)
278 (PAGES)	1 (CODE)
CR-107230 (NASA CR OR TMX OR AD NUMBER)	31 (CATEGORY)

ORBITAL/GROUND CHECKOUT STUDY

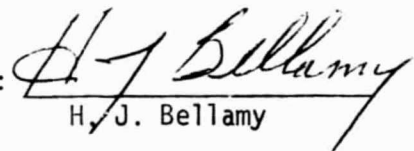
FINAL TECHNICAL REPORT

CONTRACT NAS10-6376

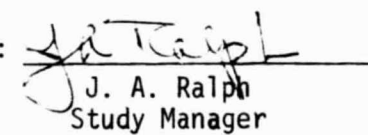
17 November 1969

69-M91-001-CKF

Prepared by:


H. J. Bellamy

Approved by:


J. A. Ralph
Study Manager

LIST OF EFFECTIVE PAGES

Insert latest changes; destroy superseded pages.

Total number of pages in this document is 278, consisting of:

<u>Page Number</u>	<u>Issue</u>
i thru xii	Original
1-1 thru 1-2	Original
2-1	Original
3-1 thru 3-256	Original
4-1 thru 4-2	Original
5-1 thru 5-2	Original
6-1 thru 6-3	Original

FOREWORD

This report summarizes a study pursuant to conceptual determination of both onboard and ground checkout systems appropriate to the Space Station/Space Base Program of 1975-85. Some consideration is also given to a 1986 Manned Mars Mission. Summary results and discussions are contained in IBM document 69-M91-002-CKF "Executive Summary Report for Orbital/Ground Checkout Study". The work was conducted by the Federal Systems Division of the International Business Machines Corporation under Contract NAS10-6376 for the John F. Kennedy Space Center of the National Aeronautics and Space Administration. Technical control and guidance was furnished by Mr. Wallace H. Boggs of the Future Studies Office at the John F. Kennedy Space Center.

Publication of this report does not constitute National Aeronautics and Space Administration endorsement of the findings or conclusions of the report.

ACKNOWLEDGMENT

H. J. Bellamy

P. Green

L. A. Jacowitz

T. F. Johnson

F. G. Kilmer

J. E. Ligocki

T. J. Meaders

R. J. Rathbun

W. Robinson

L. A. Williams

TABLE OF CONTENTS

<u>Section</u>	<u>Title</u>	<u>Page</u>
	Foreword	iii
	Acknowledgment	iv
	List of Abbreviations	x
I	INTRODUCTION	1-1
II	OBJECTIVES	2-1
III	STUDY APPROACH	3-1
	3.1 Guidelines	3-4
	3.2 Future Technology Assessment	3-5
	3.2.1 Summary	3-6
	3.2.2 Detailed Treatment	3-16
	3.3 Mission Analysis	3-74
	3.3.1 Space Station/Base Mission	3-80
	3.3.2 Manned Interplanetary Flyby Mission	3-94
	3.3.3 References - Section III	6-1
	3.4 Onboard Requirements Definition	3-106
	3.4.1 Communications Analysis	3-107
	3.4.2 Space Station/Base Requirements	3-122
	3.4.3 Vehicle Subsystem Inflight Checkout Requirements	3-132
	3.4.4 Configurations Options-Onboard	3-181
	3.5 Ground Requirements Definition	3-211
	3.5.1 Ground System Characteristics	3-213
	3.5.2 Ground System Configuration	3-219
	3.5.3 Software	3-236
	3.6 Implementation Plans	3-250
IV	CONCLUSIONS	4-1
V	RECOMMENDATIONS FOR FURTHER EFFORT	5-1
	5.1 Technology Development	5-1
	5.2 System Development	5-1
	5.3 Further Study	5-2
VI	REFERENCES	6-1
	6.1 Section 3.3 References	6-1
	6.2 Section 3.4 References	6-1

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
3-1	Integrated Circuit Technology Projection	3-7
3-2	Optical System Resolution Projection	3-10
3-3	Display Technology	3-13
3-4	Imagery Utilization	3-17
3-5	Viewing Geometry	3-20
3-6	Resolution Requirements for 1975 Versus Current Photocamera Capabilities	3-22
3-7	Future Trends in Vidicon Resolution - Less Lens	3-23
3-8	Future Trends in TV Camera Resolution	3-25
3-9	Future Trends in Sweep Linearity of TV Cameras	3-29
3-10	Imagery Collection and Retrieval System	3-30
3-11	Optical Radiometry: Coverage Requirements -VS- Current (1970) Capabilities	3-32
3-12	Advanced Multi-Band Radiometer Concept (1975-1980)	3-36
3-13	K-1877 Photo Development Rate 250 Foot-Candles Daylight Fluorescent	3-46
3-14	Simulated P11 Phosphor Characteristic Curves	3-47
3-15	Data Storage Density Trends	3-50
3-16	Display Technology	3-56
3-17	Mars Mission Profile	3-76
3-18	Manned Mars Mission Configuration	3-77
3-19	Mission Profile for Space Station Mission	3-79
3-20	Major Mission Events	3-81
3-21	1975-1985 Space Station Configurations	3-82
3-22	Space Station Experiment Operation Schedule	3-89
3-23	Experiment Timeline - Core (Typical)	3-91
3-24	Crew and Data Timeline	3-92
3-25	Flyby Mission Profile	3-96
3-26	Earth-Mars-Earth Interplanetary Trajectory	3-98
3-27	Earth Launch and Vehicle Assembly Sequence for Mars Flyby Mission	3-99
3-28	S-IV Orbit Launch Mode	3-101
3-29	Typical Mission Experiment Program Profile	3-104
3-30	Space Station to Ground Station Coverage (On Time Per Orbit)	3-109
3-31	Comparative Costs of Candidate Communications Links	3-116
3-32	Communications System Parameter Variation with Range for Mars Flyby Mission	3-119
3-33	Checkout Interfaces for Space Station Program	3-123
3-34	Program Elements for Space Station Checkout	3-124
3-35	Reliability, Maintainability and Checkout Relationships	3-126
3-36	Relative Merits of Redundancy Schemes	3-128
3-37	Rate Gyro Reliability	3-129
3-38	Horizon Scanner Onboard Test Points	3-137

LIST OF ILLUSTRATIONS (Cont)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
3-39	Star Tracker Onboard Test Points	3-139
3-40	Solar Sensor Processor Channel Onboard Test Points	3-142
3-41	Gyro Package Onboard Test Points	3-144
3-42	Rate/Attitude Computer Onboard Test Points	3-145
3-43	Checkout Operational Flow	3-150
3-44	Time Interval	3-151
3-45	Navigation and Control System Block Diagram	3-156
3-46	Navigation and Control Primary Loop	3-159
3-47	Navigation and Control Secondary Loop	3-160
3-48	Assumed Computational Timeline	3-162
3-49	Typical Multiprocessor Configuration	3-182
3-50	OCS Concept "A"	3-183
3-51	OCS Concept "B"	3-186
3-52	Remote Data Acquisition and Checkout Unit Application	3-188
3-53	OCS Concept "C"	3-191
3-54	Preferred OCS Concept for 1975 Space Station Core Module ...	3-194
3-55	Candidate 1985 Space Base Configuration	3-198
3-56	Evolutionary Trend for Space Station Test Points Monitored Onboard and by Ground Stations	3-202
3-57	Candidate Data Management System	3-208
3-58	Candidate Telemetry System	3-210
3-59	Decentralized System	3-224
3-60	Conventional Centralized System	3-225
3-61	Data Identifier System A	3-228
3-62	Data Identifier System B	3-231
3-63	Ground System Configuration	3-233
3-64	Checkout Processor Layout	3-235
3-65	System Test Display	3-245

LIST OF TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
3-1	Memory Technology for Main Memory and Control Storage	3-8
3-2	Memory Technology for Large Capacity Storage	3-11
3-3	Projected Computer State-of-the-Art for 1975	3-14
3-4	Recommendations	3-15
3-5	Effective Line Pairs for Cameras	3-19
3-6	Comparison of Resolution - 1970 and 1975 Photocameras	3-26
3-7	Comparison of Near Future (1975) Photocameras and TV Cameras	3-27
3-8	Spectrometry; Requirements -VS- Current (1970) Capabilities	3-38
3-9	Film	3-43
3-10	Key Issue - Bulk Data Storage	3-49
3-11	Controls and Displays	3-55
3-12	Switches	3-58
3-13	Message Indicators	3-60
3-14	Readouts	3-61
3-15	Meters	3-63
3-16	Dials	3-64
3-17	CRT/Operator Hand Controls	3-67
3-18	Experiments Selected for the Orbital Workshop	3-78
3-19	Experiment Program Emphasis - Time Phased	3-85
3-20	Space Station Experiment Groupings - Core	3-86
3-21	Space Station Experiment Groupings - Medium	3-87
3-22	Space Station Experiment Groupings - Balanced	3-88
3-23	Mars Flyby Typical Mission Parameters	3-97
3-24	Experiment Payload for Mars Flyby Mission	3-102
3-25	OCDMS Requirements for Space Station	3-125
3-26	Spares Required for Given Reliability Goals	3-130
3-27	Improvement in Space Station Reliability Using Redundancies and Spares	3-131
3-28	Redundancies and Spares Weights for Space Station Subsystems	3-131
3-29	Subsystem Checkout Requirements as a Function of Increasing Test Complexity	3-133
3-30	Maintenance Characteristics - GNC Sensors	3-135
3-31	Summary of Test Measurements Required for Checkout of One Horizon Scanner	3-138
3-32	Test Measurements Required for Checkout of One Star Tracker Unit	3-140
3-33	Test Measurements Required for Checkout of One Solar Sensor Channel	3-143
3-34	Test Measurements Required for Checkout of One Gyro Package	3-146
3-35	Test Measurements Required for Checkout of One Rate/Attitude Computer	3-148

LIST OF TABLES (Cont)

<u>Table</u>	<u>Title</u>	<u>Page</u>
3-36	Experiment Data Handling Utility Routines	3-165
3-37	Experiment Scheduling Data Base	3-167
3-38	Experiment Executive Storage Requirements	3-169
3-39	Total Experiment Program Storage Requirements	3-169
3-40	Inventory Data Base Storage Requirements/Item	3-172
3-41	Inventory Management Storage Requirements	3-173
3-42	Main and Bulk Storage Allocations	3-179
3-43	1975-80 Computer System Requirements	3-180
3-44	Advantages and Disadvantages of Concept "A"	3-185
3-45	Advantages and Disadvantages of Concept "B"	3-189
3-46	Advantages and Disadvantages of Concept "C"	3-192
3-47	Advanced Space Station Computer Element Characteristics	3-195
3-48	Space Station Experiment Evolution from 1975-1985	3-200
3-49	Evolution of Experiment Data Management System	3-201
3-50	Evolution of Space Station Computer	3-204
3-51	Man/Machine Interface	3-205
3-52	Present KSC Computer Capability	3-214
3-53	Checkout Signal Summations	3-216
3-54	Measurements	3-221
3-55	Composite Processor	3-222
3-56	System Characteristics	3-229
3-57	Routing and Switching Unit Characteristics	3-234
3-58	Computer Processor Characteristics	3-237
3-59	Future Requirements and Responses	3-238
3-60	Software Systems - Present and Projected	3-241
3-61	Tutorial System Control	3-244
3-62	Software Requirements	3-247
3-63	SDS 930 Transition Plan	3-252
3-64	GE 635 Transition Plan	3-254
3-65	Recommendations	3-255

LIST OF ABBREVIATIONS

<u>Abbreviation</u>	<u>Definition</u>
AAP	Apollo Applications Program
ACE-S/C	Acceptance Checkout Equipment - Spacecraft
A/D	Analog-to-Digital
ADAP	Adaptive Intercommunication Control Subroutine
AEC	Atomic Energy Commission
AGC	Automatic Gain Control
AGR	Agricultural
A/N	Alphanumeric
ASTRO	Astronomical
ATM	Atmospheric & Apollo Telescope Mount
ATOLL	Acceptance Test or Launch Language
ATS	Application Technology Satellite
AU	Astronomical Unit
AVCS	Advanced Vidicon Camera System
AZ/RG	Azimuth/Range
BITE	Built-In Test Equipment
BW	Bandwidth
B&W	Black and White
CIF	Central Instrumentation Facility
CKF	Cape Kennedy Facility (IBM)
CLASP	Computer Language for Aeronautics and Space Programming
CMG	Control Moment Gyro
C/O	Checkout
COMSAT	Communications Satellite
CPU	Central Processor Unit
CRT	Cathode Ray Tube
CSM	Command Service Module
CSS	Computer System Simulation
DDA	Digital Data Adapter
DEE-6	Discrete Events Evaluator
D&R	Distribution and Rotation Laws
DRSS	Data Relay Satellite System
DSIF	Deep Space Instrumentation Facility
ECO	Electrical Checkout
ECS	Environmental Control System
EDS	Emergency Detection System
EEM	Earth Entry Module
EL	Electroluminescent
EPR	Electrical Power Reactor
ERM	Earth Reentry Module
ERPS	Earth Return Propulsion System
ESE	Electrical Support Equipment
EVA	Extra Vehicular Activity
FORTTRAN	Formula Translator
FPS	Feet per second
FSC	Federal Systems Center (IBM)

LIST OF ABBREVIATIONS (Cont)

<u>Abbreviation</u>	<u>Definition</u>
GEOG	Geographical
GEOL	Geological
GG	Gyro Gimbaling
GPSS	General Purpose System Simulation
GS-DRSS	Ground System - Data Relay Satellite System
GSE	Ground Support Equipment
HF	High Frequency
HRIR	High Resolution Infrared Radiometer
HS	Horizon Scanner
IBM	International Business Machines Corporation
IC	Integrated Circuit
ID	Interface Document
IMBLMS	Integrated Medical Behavioral Laboratory Measurement System
INTELSAT	International Telecommunication Satellite
I/O	Input/Output
IR	Infrared
ISCP	Integrated Station Control Panel
IU	Instrument Unit
K	Thousand
KSC	John F. Kennedy Space Center
LCC	Launch Control Center
LED	Light Emitting Diode
LP	Line-Pair
LSI	Large Scale Integration
LSS	Launch Support System
L/V	Launch Vehicle
MCC	Mission Control Center
MCM	Mission Crew Module
MCS	Mars Capture Stage
MEM	Martian Excursion Module
M&O	Maintenance and Operations
MRIR	Medium Resolution Infrared Radiometer
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
MSI	Medium Scale Integration
MSOB	Manned Spacecraft Operations Building
MSSR	Mars Surface Sample Return
MTTR	Mean Time to Repair
NASA	National Aeronautics and Space Administration
NASO	National Astronomical and Solar Observatory
NM	Nautical Mile
OAO	Orbiting Astronomical Observatory
OART	Office of Advanced Research and Technology
OCDMS	Onboard Checkout and Data Management System
OCEAN	Oceanographic
OCS	Onboard Computer System

LIST OF ABBREVIATIONS (Cont)

<u>Abbreviation</u>	<u>Definition</u>
OSO	Orbiting Solar Observatory
PAM	Pulse Amplitude Modulation
PCI	Projection Cue Indicator
PCM	Pulse Code Modulation
PRU	Primary Replaceable Unit
RACU	Remote Data Acquisition and Checkout Unit
RAR	Rapid Access Recording
RAU	Remote Data Acquisition Unit
RCC	Remote Checkout Computer
RCS	Reaction Control System
RF	Radio Frequency
RPM	Revolutions per minute
RMS	Root means square
ROS	Read Only Storage
RTCC	Real Time Computer Complex
S/C	Spacecraft
SM	Statue mile
SPT	Spectrographic Telescope
SRU	Secondary Replaceable Unit
SSU	Switchable Selector Unit
SVDSS	Space Vehicle Data Systems Synthesizer
TEL IV	Telemetry Receiving Ground Station on KSC
TQR	Torquer
TR	Transmit and Receive
T ² L	Transistor - Transistor Logic
TV	Television
USB	Unified S-Band
UV	Ultra Violet
X-POP	X - Axis is Perpendicular to Orbit Plane

SECTION I

INTRODUCTION

This conceptual study analyzed the checkout and data management system requirements anticipated for the 1975-85 Space Station/Space Base program. A 1986 Mars mission was also considered. In the light of expected technology advances, system concepts (both onboard and ground-based) were developed to satisfy the expected requirements. An implementation plan for the preferred concept of the ground-based system is presented. The study contract was initiated on January 17, 1969 with a performance period of eight months. This period was extended two additional months by contract amendment to accommodate the incorporation of information resulting from developments in the two concurrent Space Station Definition Studies.

Phase I of the study consisted of an analysis of the anticipated Space Station/Space Base mission leading in turn to a definition of requirements for the onboard system. The data management requirements were defined for guidance and navigation, attitude control, experiments, displays, as well as the checkout function.

Phase II entailed development of onboard system concepts which satisfied the derived requirements. The concepts developed take maximum advantage of the expected available technology. A projection of which was also conducted in this study phase. Other determinants, such as earlier system designs, operational experience, and commodity availability were also considered.

Phase III consisted of the development of concepts for the ground-based system which were compatible with the onboard concepts and made efficient use of the applicable technology as projected. The other determinants of the onboard configuration were also considered.

Phase IV of the study entailed selection of preferred concepts for both the onboard and ground systems and their development to a system architecture level. Trade studies were performed in necessary areas. System increments uniquely necessary for the planetary mission were also developed.

Phase V consisted of an analysis of present ground system capabilities and the formulation of a system implementation plan which permits orderly evolution into a configuration necessary for the support of post-Apollo missions.

SECTION II

OBJECTIVES

The primary study objective was the development of checkout system concepts applicable to the 1975-85 NASA manned missions which will be substantially unaffected by subsequent program detail definition activity. Specifically, the study was addressed to the following:

- o An assessment of technology advances applicable to instrumentation, communication, checkout and data management systems for two projected NASA space programs:
 - 1975-85 Space Station/Space Base
 - 1986 Manned Planetary Flyby.
- o The conceptual development of onboard and ground checkout systems required to support both programs
- o The development of a time-phased plan for ground system transition to accommodate the projected onboard capability.

SECTION III

STUDY APPROACH

The study approach was based on a progression through three interrelated analytical activities for the two mission classes:

- o Mission analysis and requirements definition
- o Onboard checkout and data management systems conceptual development
- o Ground-based equipment conceptual development.

The study was conducted with a continual consideration of expected electronic system technology growth in the time frame of interest. The particular tasks and their interrelationships are as follows:

1. The technology assessment task entailed a comprehensive analysis of available technology projections for the 1975-85 decade. Electronic technology capability extrapolations were stressed including those pertaining to integrated circuits, computer memory, control systems, mass storage, and display methodology. Onboard experiment equipment technology including expected optical system capabilities was also investigated. A forecast of expected computer software developments is included.
2. The mission analysis task addressed both the manned-interplanetary mission and the orbital-space station mission projected for the time frame of interest. Experiment grouping, vehicle mission timelines, onboard crew functions, and communications visibility were postulated.

3. The requirements definition task, which included both the flight requirements and the preliminary prelaunch requirements, used the output of the mission analysis task as a starting baseline. An estimate was made in the magnitude range of the numbers and types of parameters that define the checkout/data management requirements for the experiments and vehicle subsystems.

Simultaneously, a preliminary assessment of the prelaunch requirements was made. However, these requirements are somewhat dependent upon the actual onboard configuration. This subtask represents, therefore, an initialization of the prelaunch requirements.

4. The onboard system configuration analysis task consisted of the iterative process of configuration analysis which is heavily influenced by predicted technology and the effects and degree of orbital ground support. Tradeoffs were made between onboard and ground performance of checkout/data management functions and between centralized and decentralized onboard configurations. As these tradeoffs were performed, the requirements were reassessed in an iterative process. Particular attention was devoted to digital computer technology and capabilities which exert a major shaping force on the onboard equipment. With the trade studies completed and candidate onboard configurations selected, the prelaunch requirements were determined.
5. The prelaunch system configuration analysis was then conducted. After the prelaunch requirements had been determined, and based upon the inflight and ground checkout operational and equipment needs, this second iterative analysis determined the primary prelaunch configuration candidates. Technology predicted to be available for the ground-based

equipment was the other determinant.

6. The selection of preferred concepts was the next task. It entailed the assessment of the total systems configuration, both prelaunch and flight. selected to represent varying mixes of onboard and ground prelaunch checkout capability. As a basis for study conclusions, the criteria for final selection is cost effectiveness, graceful degradation and flexibility to handle changing mission requirements.
7. The final task encompassed a ground checkout system capabilities analyses which provide a baseline for the transition to the 1975-85 system concepts. Existing and presently planned capability of ground-based equipment was analyzed leading to a recommended system implementation.

3.1 GUIDELINES

The following guidelines are those used in the study. They involve considerations of desired degree of onboard autonomy, ground dependency, trade study priorities and expected degree of system detail exposition for the preferred concepts.

- o Nonelectronic requirements will be developed as required only to define checkout requirements.
- o Function allocations between ground and orbital systems are made in accordance with operational requirements.
- o Checkout system concepts making maximum use of expected technology advances will be developed to a system architecture level.

3.2 FUTURE TECHNOLOGY ASSESSMENT

In order to define reasonable configurations for onboard and ground-based systems having instrumentation and communication system interfaces, it is appropriate to focus initial attention on the computer systems architectural possibilities followed by an assessment of instrumentation and communication system technologies. In the process of structuring a computerized checkout/data management system, a number of major design options are available with respect to system architecture. As an initial starting point, consideration must be given to the manner of distribution of the major processing function. Should a decentralized approach be taken wherein the systems monitored are serviced by a substantially independent hardware and software subsystem, or should centralization be opted for wherein a single general purpose computer does all? Further, is the ground solution different from the onboard? And, in either case, is there a compromise solution between these two disparate system arrangements wherein the advantages of both are preserved? Without performing a realistic technology projection in both hardware and software to determine the expected subsystem capability, this fundamental decision cannot be intelligently made. Additional technology projections in such related fields as image processing and data storage are also essential to the development of a coherent system structure.

The availability of advanced technology is a function of launch date which determines the necessary design completion date. The 10-year Space Station life time, however, suggests initial system designs which provide retrofit capability later to take advantage of forecasted technology maturation. By using this approach throughout the manned-orbital program, anticipated technology advances can be further exploited. In those instances where a particular technological capability is necessary or desirable for Space Station utilization but where commercial market pressure is not sufficient to produce a compatible maturation date, Governmental encouragement should be considered.

3.2.1 Summary

The degree of sophistication that can be put into the restricted volume of a spacecraft obviously depends on the circuit density of the electronic components. Fortunately, spacecrafts are getting larger while circuits are getting smaller. As Figure 3-1 shows, the Space Station core module will use Medium Scale Integration (MSI) at about 30-40 circuits per chip area.

Integrated circuit technology is presently advancing by an order of magnitude every seven years, indicating that for the Space Base and the Manned Mars Mission, Large Scale Integration (LSI) will be in use extensively. It is hard to predict what will happen between 1981 and 1985 because of the seemingly insurmountable problems associated with fabrication, cooling and testing. This may cause a flattening effect in the curve unless breakthroughs occur in these fields.

Medium and large scale integrated circuits using bipolar and field effect transistor arrays also form the emerging technology for computer memory applications. The dominant magnetic core technology now will give way gradually in ground-based equipment, but its susceptibility to magnetic fields will make earlier replacement more attractive in airborne computers. Table 3-1 shows the significant technologies that have been and are being used for main memory. It is important to note that, although monolithic semiconductor technology offers the best cost/performance factor, the radiation hardened feature of plated wire memories may be a vital advantage in the space environment.

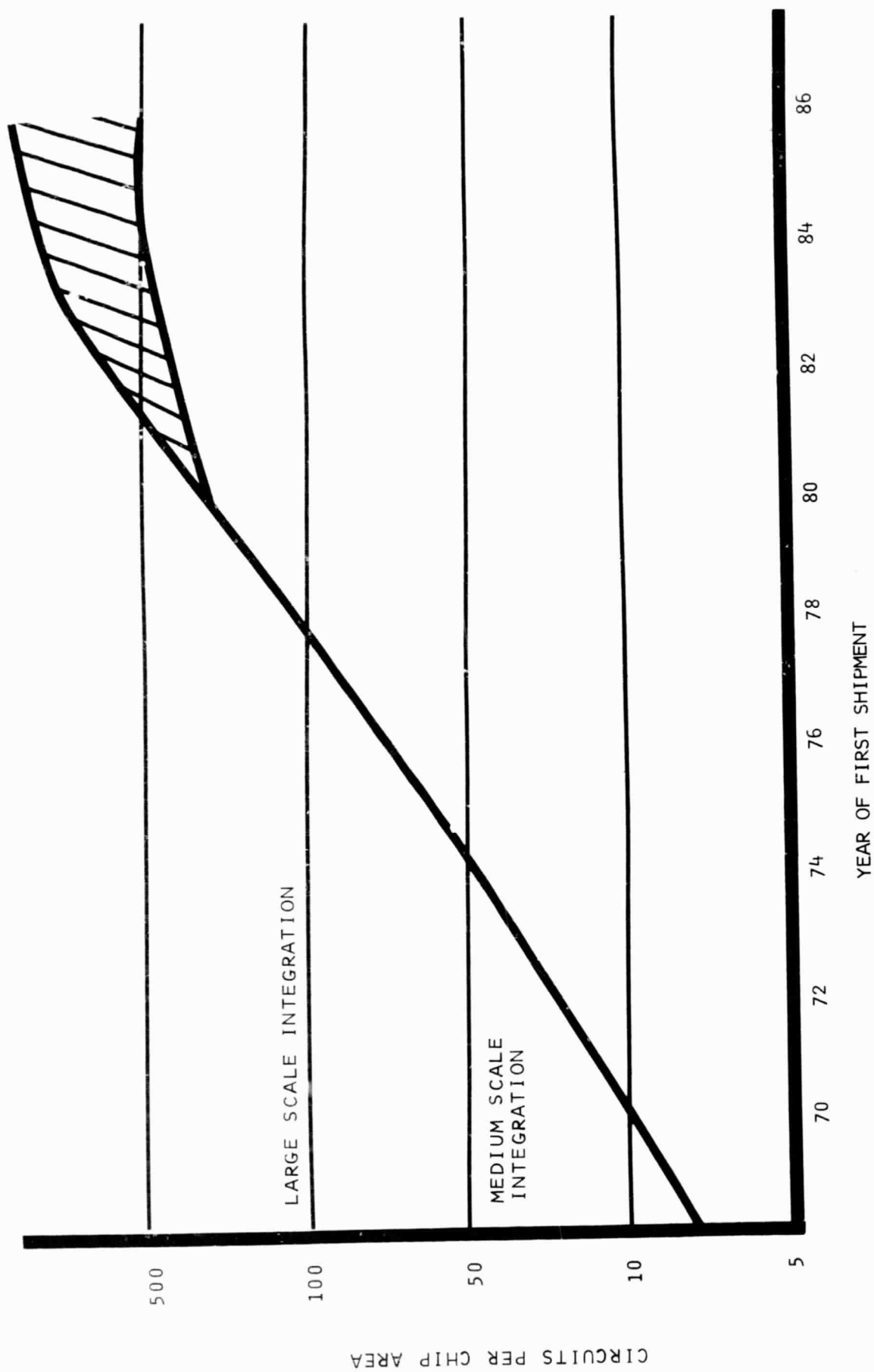


Figure 3-1. Integrated Circuit Technology Projection

Table 3-1. Memory Technology for Main Memory and Control Storage

o	Monolithic Semiconductor Array	o	Good cost/performance
		o	Error correction coding very effective in increasing reliability
		o	Nondestructive read and electrical alterability
o	Delay Lines	o	Phasing out completely
o	Ferro-Electrics	o	Aging and stability problems have not been adequately resolved
o	Tunnel Diodes	o	Inferior to other technologies in cost and performance
o	Ferrite Cores	o	Offers less advantage than thin films and monolithic semiconductors in terms of power density and speed factors
o	Plated Wire	o	Power speed - improvement over discrete ferrite cores
		o	Radiation hardened
o	Transformers and Capacitors	o	Continued exclusive use for read only storage

In general, a different technology is required to solve the problems associated with bulk memory (see Table 3-2). Unlike main memory and control storage, three technologies are being developed that offer great promise for the future. Within the next few years and possibly by 1973, thin film bulk storage will be commercially available. By 1985, research in holographic storage will have matured, offering tremendous capacities and ultra-fast access times, but laser may have to compete with ovonics. Named after its discoverer Ovshinsky, this technology is based on the diode-like properties of amorphous semiconducting material. It is fabricated as a thin film, and since it has no regular crystalline structure, its properties are unaffected by X-Ray or Gamma Ray bombardment. Although largely undeveloped, ovonics appears to be the best potential memory device for aerospace applications.

Figure 3-2 shows the anticipated development of TV vidicon tubes and metric cameras from the present to 1985. The number of resolvable elements expressed in line pairs per millimeter is proportional to the distance between objects on the ground expressed in feet. For example, today's 12-inch metric camera at an altitude of 250 miles can resolve objects 100 feet apart. Some of the earth resource requirements are plotted based on this altitude showing that expected technological growth will not keep pace with some demands. Also, resolution requirements are expected to become more stringent by 1985 (10 feet at 250 miles). Vidicons with a 9-inch format and a resolution capability consistent with projected requirements may become available in 1980 provided that the transition from an analog to digital sweep can be made in time.

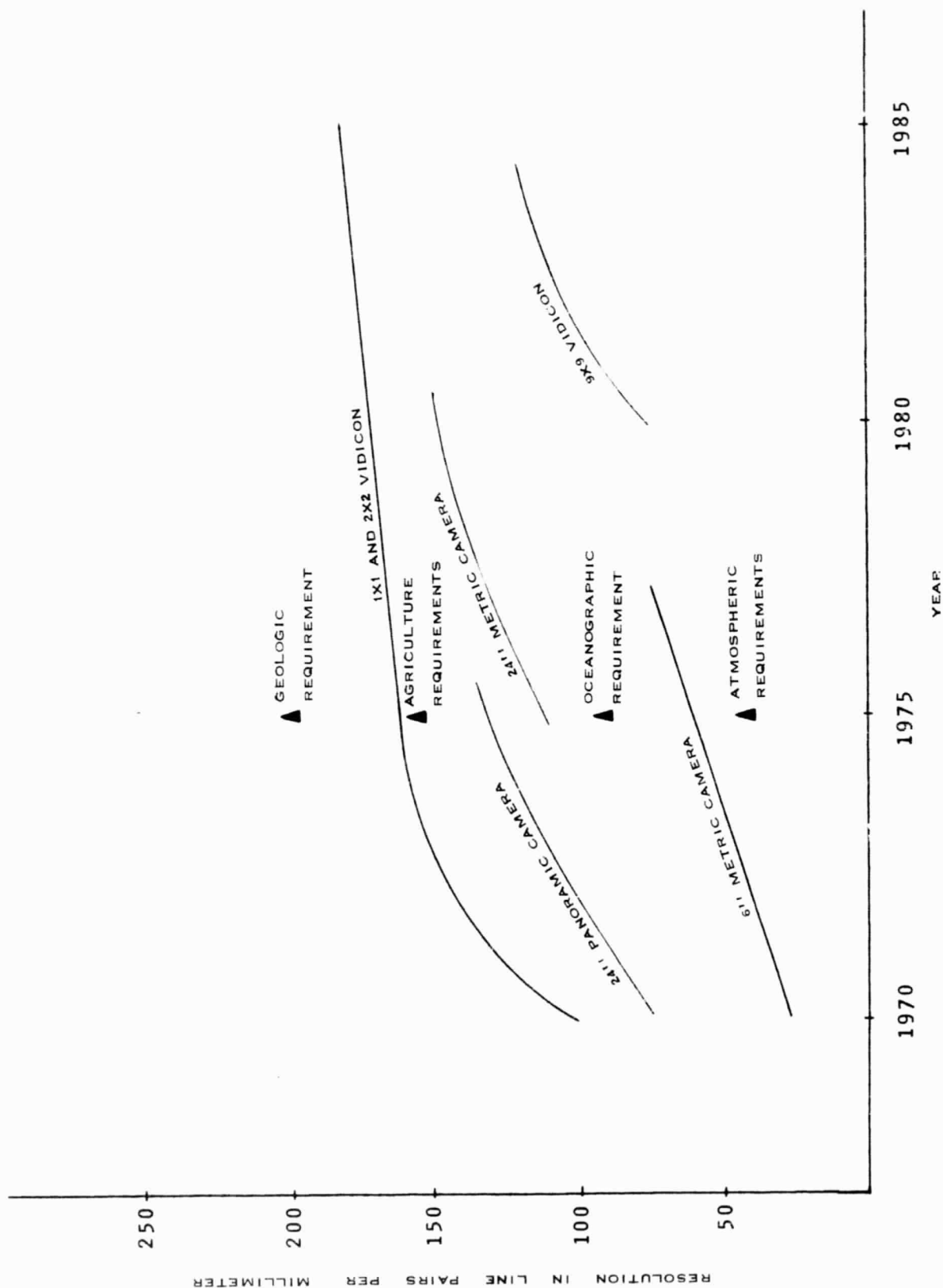


Figure 3-2. Optical System Resolution Projection

Table 3-2. Memory Technology for Large Capacity Storage

o Thin Film	o Low cost and power dissipation very suitable for bulk storage (10^6 bits/substrate)
	o Can be used for main memory application
o Batch Ferrite	o Power speed improvement over discrete ferrite cores
	o Inferior to thin films in terms of drive power, pulse propagation, and switching mechanism
o Superconductors	o No unique advantages over thin films
	o Many technical problems arise because of the very low temperatures involved
	o The cryogenic tunneling phenomenon may prove useful in some novel applications
o Beam Addressable Technologies	o Offers the greatest density potential (2.5×10^6 bits per square inch)
o Ovonics	o The best potential memory device
	o Resistant to X-Ray and Gamma-Ray radiation
	o Not presently under extensive development
	o High fabrication cost, particularly in the near term environment

Figure 3-3 shows the development trends for cueing indicators and readout devices. By the time the Space Station core module is launched, the light emitting diode array could become a successor to the incandescent lamp because of its high brightness, low voltage efficiency, and monolithic fabrication. Holographic displays will come into being by 1980 if their development is accented. Development to date has primarily addressed the construction of holograms and long-term storage of holographic data. The real-time application of holograms for image construction requires extensive development activity.

By using results from the future technology study (see Table 3-3), it is possible to size the two computer types anticipated to be onboard the Space Station. The executive machine is a group of modules connected to perform as a multiprocessor. Only 15 cubic feet, which is less than 0.15 percent of the total Station volume, are required for all units including the I/O channels. The smaller remote checkout computers also require an insignificant amount of space, but there may be as many as 10 of them. It is easily seen that the most serious limitation is the electrical power that must be supplied to run the computers. For a station with 25 kw average bus power, almost 25 percent of it would be required for the onboard computers. It must be stressed, though, that all the figures were chosen to be somewhat pessimistic.

In each of the key areas listed in Table 3-4, there is a technology "gap." Pressures from the commercial market will not be sufficient to develop these technologies for spacecraft application. Research in these fields should be accelerated to ensure an adequate technology base for both the near-term and long-term missions.

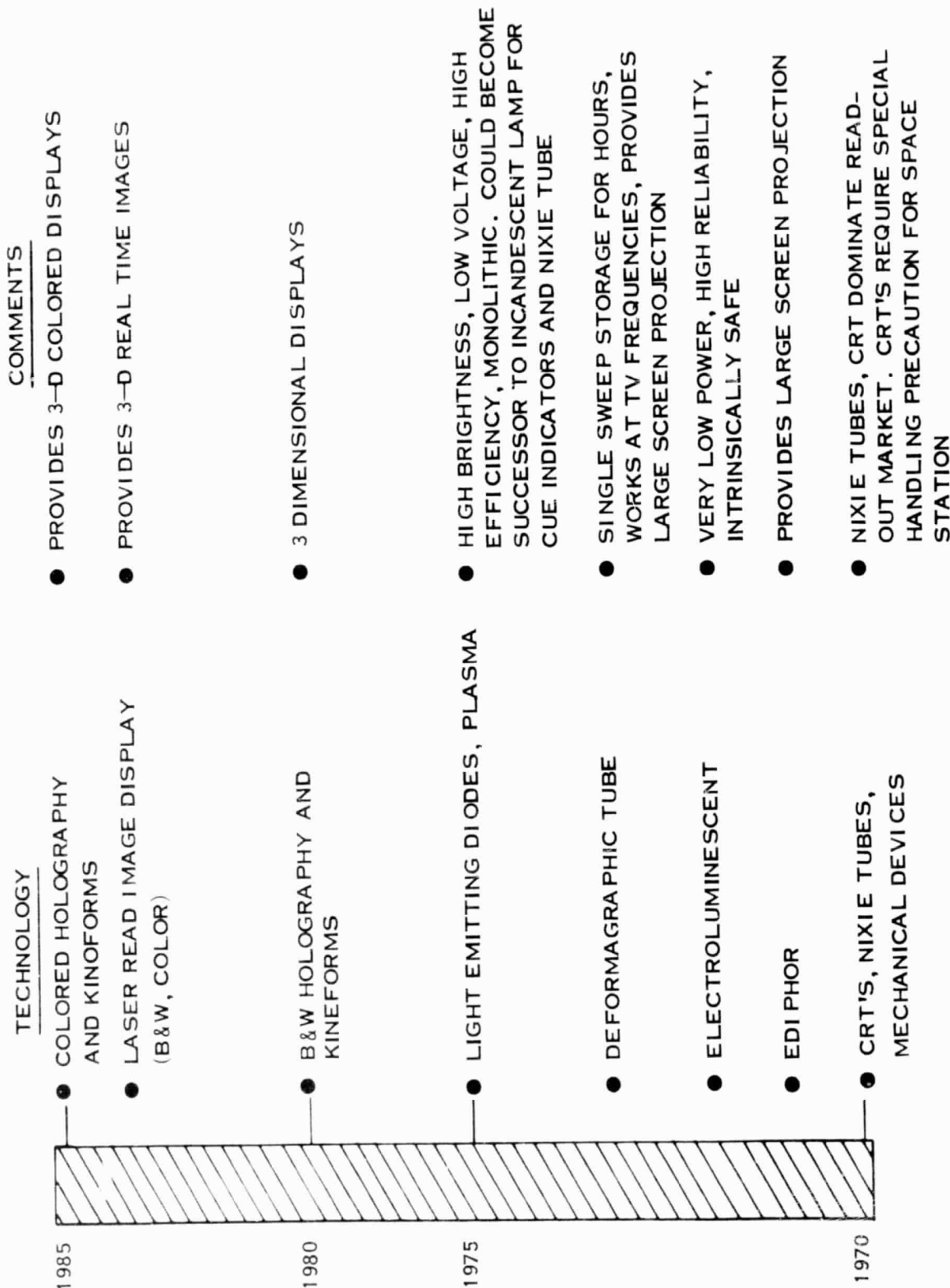


Figure 3-3. Display Technology

Table 3-3. Projected Computer State-of-the-Art for 1975

<u>Feature</u>	<u>Executive Computer</u>
Architecture	Parallel processor
Speed	600,000 instructions/second
Memory	256K X 32 bit words
Volume	15 FT ³ , includes all accessory modules
Weight	500 pounds, includes all accessory modules
Power	1000 watts, includes all accessory modules

Table 3-4. Recommendations

- o Encourage development of all electronic bulk storage.
- o Investigate potential of ovonic technology for space applications.
- o Determine optimum computer architecture for spacecraft applications by studying possible parallel processing systems.
- o Encourage development of coherent optical communication systems.
- o Develop real time holographic image construction techniques.
- o Develop camera and television technology to meet 1985 resolution requirements.

3.2.2 Detailed Treatment

3.2.2.1 Image Processing

As the early Space Station evolves toward an autonomous base or laboratory, there will be an increasing demand for image data from experiments (see Figure 3-4). Initially, there will be 10^{12} bits/day generated by the 1975 Space Station which is expected to grow to 10^{14} bits/day by 1985. Historically, this data has been collected either on film or transmission of video pictures on RF links. Using photographic techniques, there will be 3000 pictures/day requiring analysis in 1975 alone. If, on the other hand, this information is transmitted to the ground through use of a vidicon tube, it will require 15,000 hours of computer time per day.

The solution to this problem lies in reduction and analysis of the raw imagery data onboard the Space Station. The reduced data, which represents two orders of magnitude less information, can then be returned to the ground through physical film return or RF transmission. A transition plan to implement this solution is as follows:

1975 - Primary:	Return of undeveloped film to ground
Secondary:	Telemetered raw data
1980 - Primary:	70% 1975 techniques
Secondary:	30% direct onboard analysis
1985 - Primary:	90% direct onboard analysis
Secondary:	10% 1975 techniques.

Optical sensors form the large majority of image producing sensors for the 1975-1985 Space Station application. Included in this grouping are:

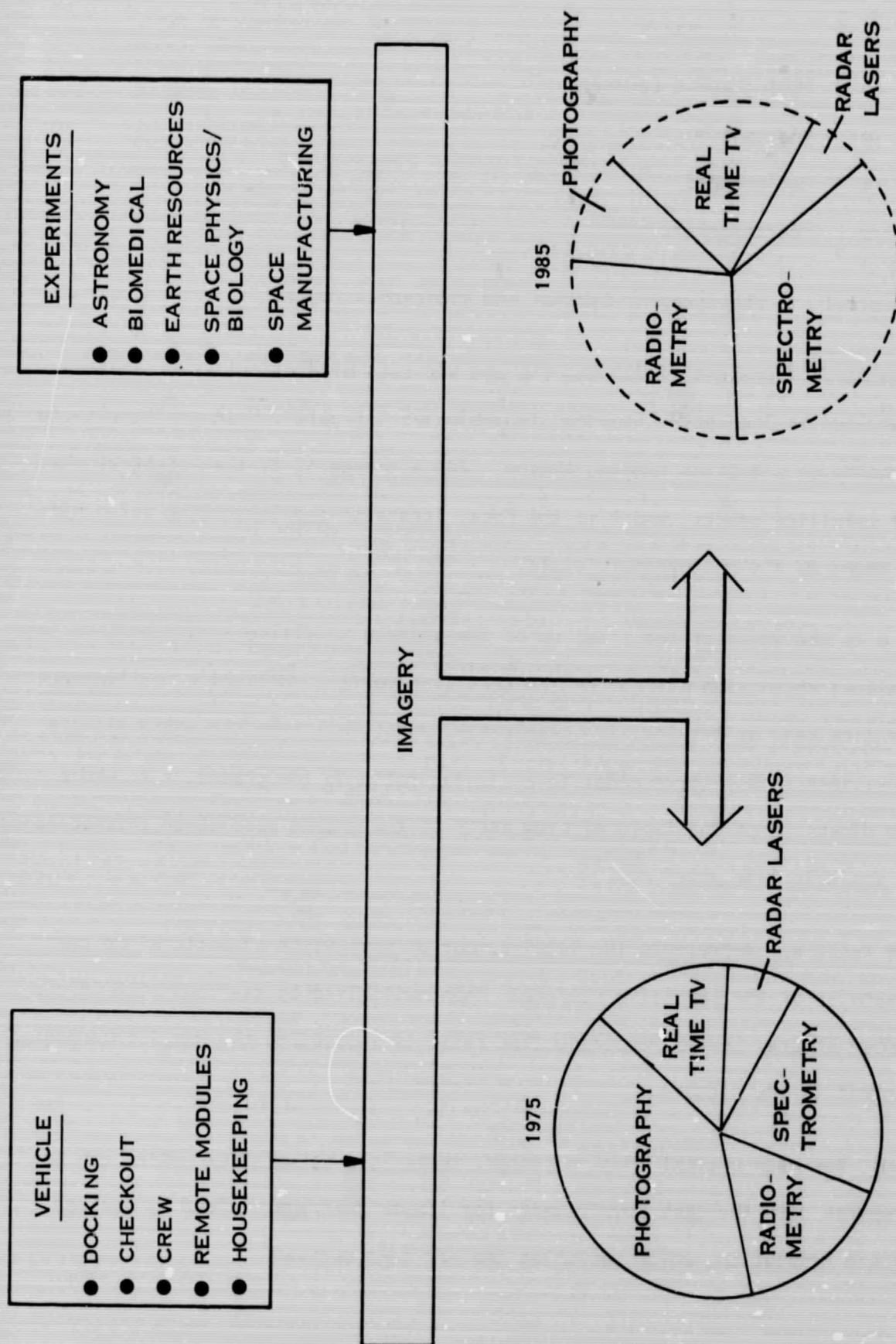


Figure 3-4. Imagery Utilization

- o Photographic Cameras
- o Vidicons
- o Radiometers
- o Spectrometers.

3.2.2.1.1 Photographic Cameras and Vidicons - Present

A summary of present (1970) cameras and vidicons with effective resolution expressed in line pairs is shown in Table 3-5. Figure 3-5 shows the viewing geometry of a typical imaging sensor. The altitude h , is the height at which the satellite orbits, and f is the focal length of the lens. The ratio h/f is known as the photographic scale.

If d is the width of the film, or of the vidicon sensitive area, and ρ is the smallest resolution element of the sensitive surface (defined as millimeters per line pair at the limiting resolution condition), then the ratio d/ρ (in consistent terms) corresponds to a similar ratio on the ground, a/r , where a is one dimension of the field of view and r is the ground resolution corresponding to a single line pair.

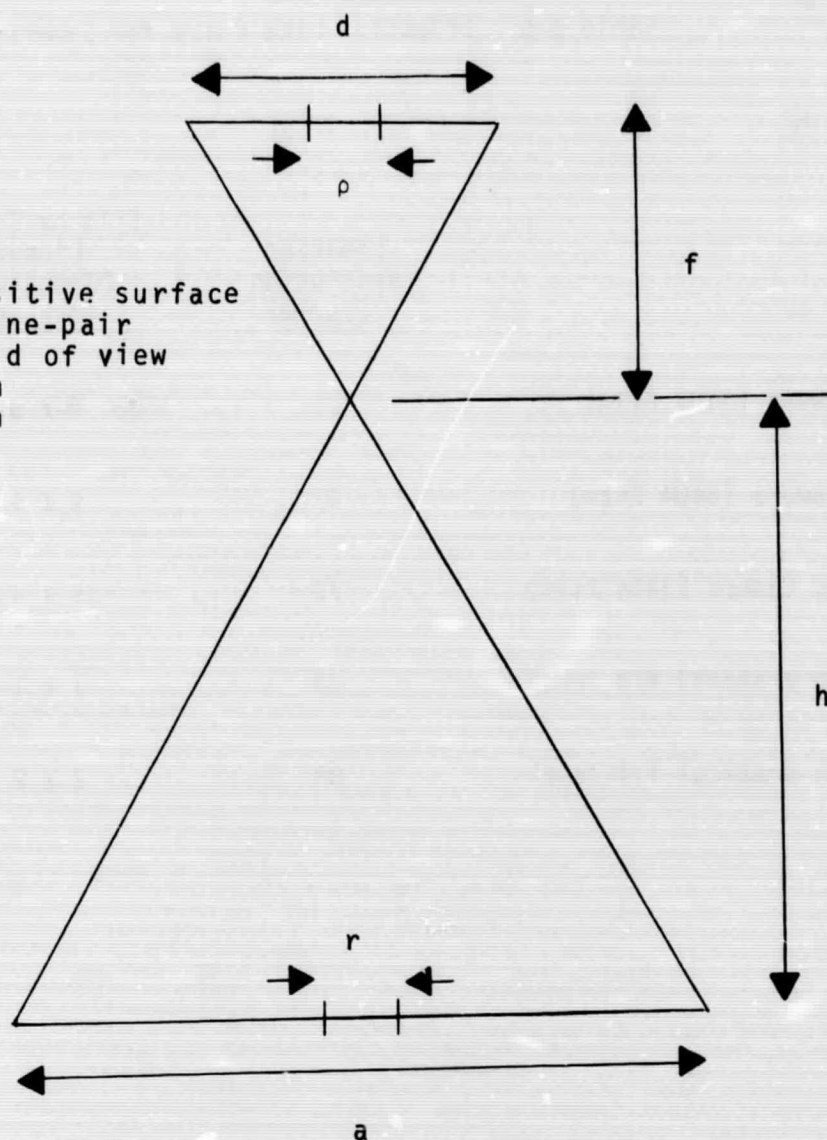
The ratio d/ρ represents the total number of resolvable elements along one dimension of the sensitive surface. When multiplied by the logarithm of the number of gray levels required, this ratio is related to the total information content in the picture.

Thus, for each optical imaging sensor, there is a value of d/ρ which can be compared with the task requirements for linear coverage divided by desired ground resolution, which resembles the a/r term derived.

Table 3-5. Effective Line Pairs for Cameras

	<u>Limiting Resolution (lp/mm)</u>	<u>Film or Screen Linear Dimensions (inches)</u>	<u>Total Line-Pairs</u>
6" Metric Camera (3404 Film)	29	9 X 9	6,600
12" Metric Camera (3404 Film)	42	9 X 9	9,600
24" Panoramic Camera (3404 Film)	72	35 X 4.5	64,000
Vidicon (with practical f/4 lens)	88	1 X 1	2,240
Vidicon (with practical f/4 lens)	88	2 X 2	4,480

d=dimension of sensitive surface
 ρ=dimension of 1 line-pair
 a=dimension of field of view
 r=ground resolution
 f=lens focal length
 h=altitude



$$\frac{d}{\rho} = \frac{a}{r}, \quad \frac{h}{f} = \frac{a}{d}$$

Information Content, $H = \frac{a}{r} \log_2 G$ where G is desired number of grey level

Figure 3-5. Viewing Geometry

The user requirements for the parameter or area-to-resolution ratio range from about 300 to more than 100,000 units. The d/ρ content (number of resolvable elements) of a number of automated and manned sensors including the AVCS, the 1-inch x 1-inch and 2-inch x 2-inch vidicons, the Lunar Orbiter camera, and three film cameras are superimposed on Figure 3-6. These cameras show increasing d/ρ capabilities in the order mentioned. The two vidicon cameras have a significant capability; however, the film cameras show maximum capability to record information on a single frame.

The resolution requirements in the 1975 time frame range from 3 to 10,000 feet. Superimposed on the resolution requirements in Figure 3-7 are the resolution capabilities of film cameras, the 24-inch panoramic, and 12-inch and 6-inch metric cameras assuming an altitude of 250 statute miles.

The 6-inch metric camera can meet only a small portion of the resolution requirements; there is an improved match of capabilities with the 12-inch and the 24-inch cameras. No camera under development can meet the requirement for resolution of less than 30 feet.

Aerial coverage requirements vary from 20 to 100 miles square, with some tasks in the atmospheric sciences area requiring larger synoptic coverage. The cameras from 250 miles altitude have capabilities ranging from 47-mile x 450-mile rectangles for the 24-inch panoramic camera to 187-mile and 382-mile coverage for the 12-inch and 6-inch metric cameras. The vidicons have capabilities of about 50 statute miles; the Lunar Orbiter camera has 90 statute mile coverage (panoramic mode); and the AVCS and SPT cameras have synoptic coverage of about 150 and 700 miles, respectively. Thus, all of the sensors which have been described have inherent capability to meet most of the 1975 time frame requirements for aerial coverage with the exception of the vidicons which are marginal.

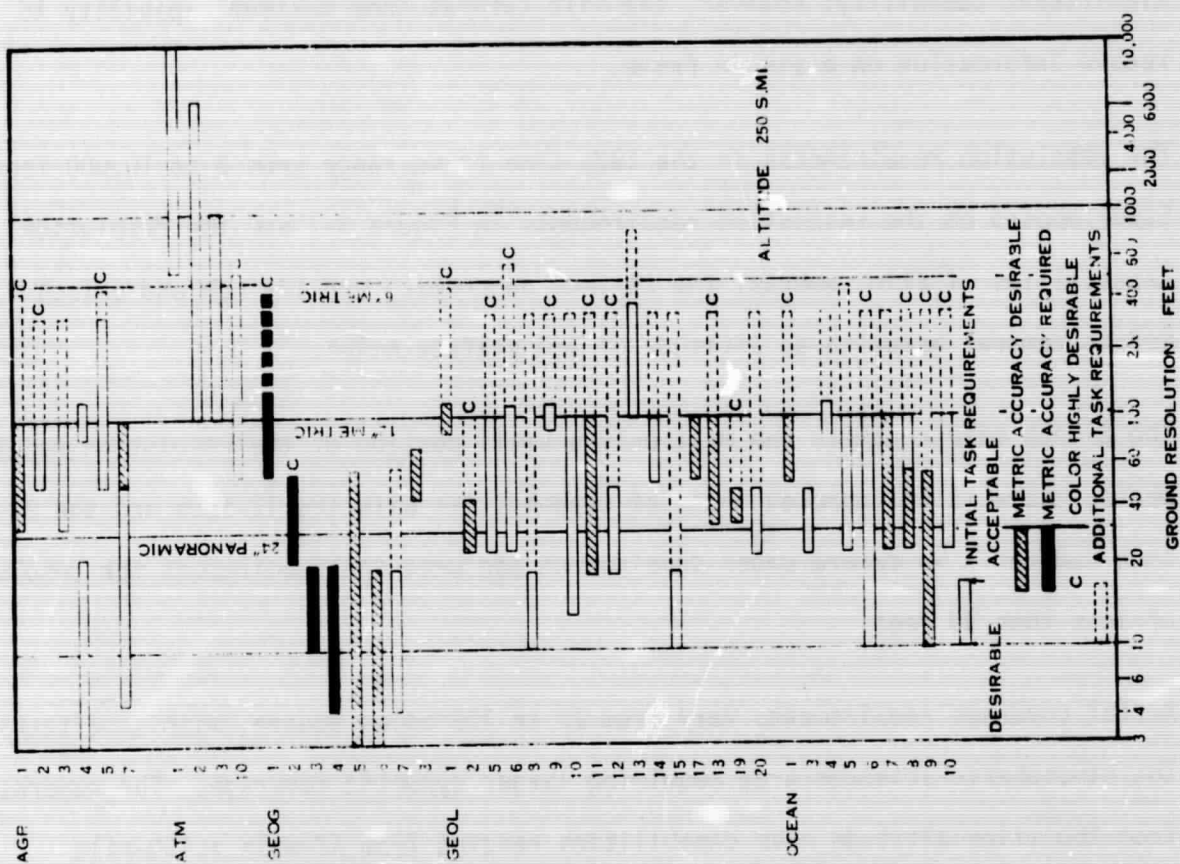


Figure 3-6. Resolution Requirements for 1975 Versus Current Photocamera Capabilities

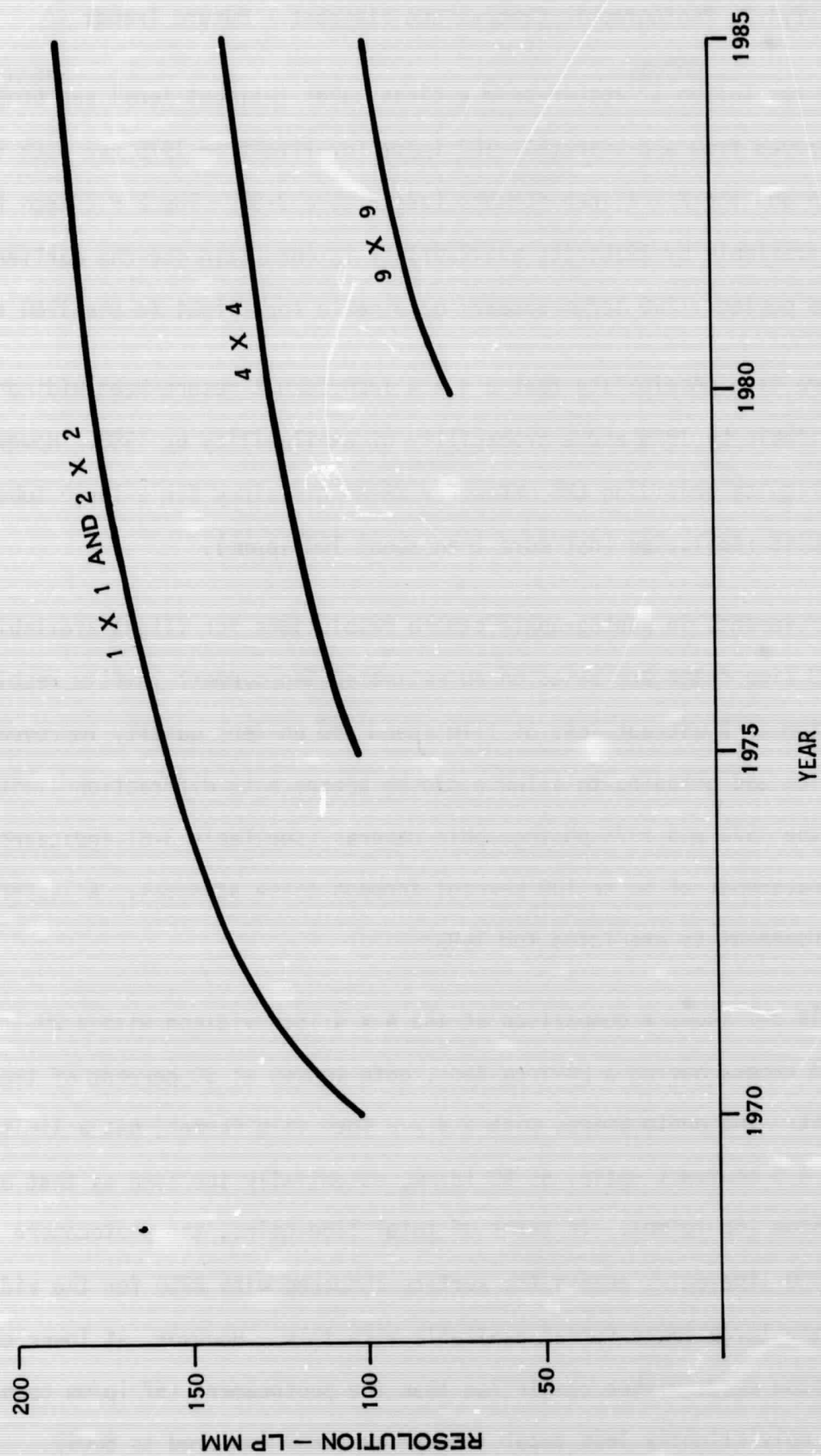


Figure 3-7. Future Trends in Vidicon Resolution - Less Lens

3.2.2.1.2 Photographic Cameras and Vidicons - Future Trends

The resolution of return-beam vidicon tubes (without lens) can probably be improved from approximately 100 lp/mm for flight in 1975 for both the 1 x 1 inch and the 2 x 2 inch formats (see Figure 3-8). The 2 x 2 inch format will be available by 1975; its availability is uncertain for the earlier (1970) time period. 200 lp/mm appears obtainable for flight in the 1980 time frame.

There is a possibility that a 4 x 4 inch format return-beam vidicon will be available by 1975 and a probability of availability by 1980. However, the difficulty providing the necessary sweep circuitry for a large tube results in reduced resolution (not more than about 100 lp/mm).

Improvements in photographic camera resolutions for flight availability in the 1980 time frame are based on an estimated improvement in film resolution by a factor of 2 without loss of film speed and on lens quality improvements through design and grinding to allow a closer approach to diffraction limits. Comparison of the 1970 and 1975 photographic cameras (see Table 3-6) indicates resolution improvements of 50 to 100 percent through these advances. A lesser degree of improvement is predicted for 1985.

Table 3-7 shows a comparison of the 4 x 4 inch vidicon with a 20-inch lens with a film camera having a 24-inch lens, both lenses at 50 percent of the diffraction limit. The photocamera, with a 9 x 9 inch film format, has a limiting resolution (at 1.3 contrast ratio) of 90 lp/mm, essentially the same as that of the 4 x 4 vidicon (88 lp/mm). In terms of total line-pairs, the photocamera resolves 20,600 line-pairs across its surface compared with 8950 for the vidicon, indicative of the large image format available with film. However, at lower contrast the vidicon shows higher resolution than the photocamera (57 lp/mm compared to 35 lp/mm) and only slightly less total line-pairs (5800 compared to 8000).

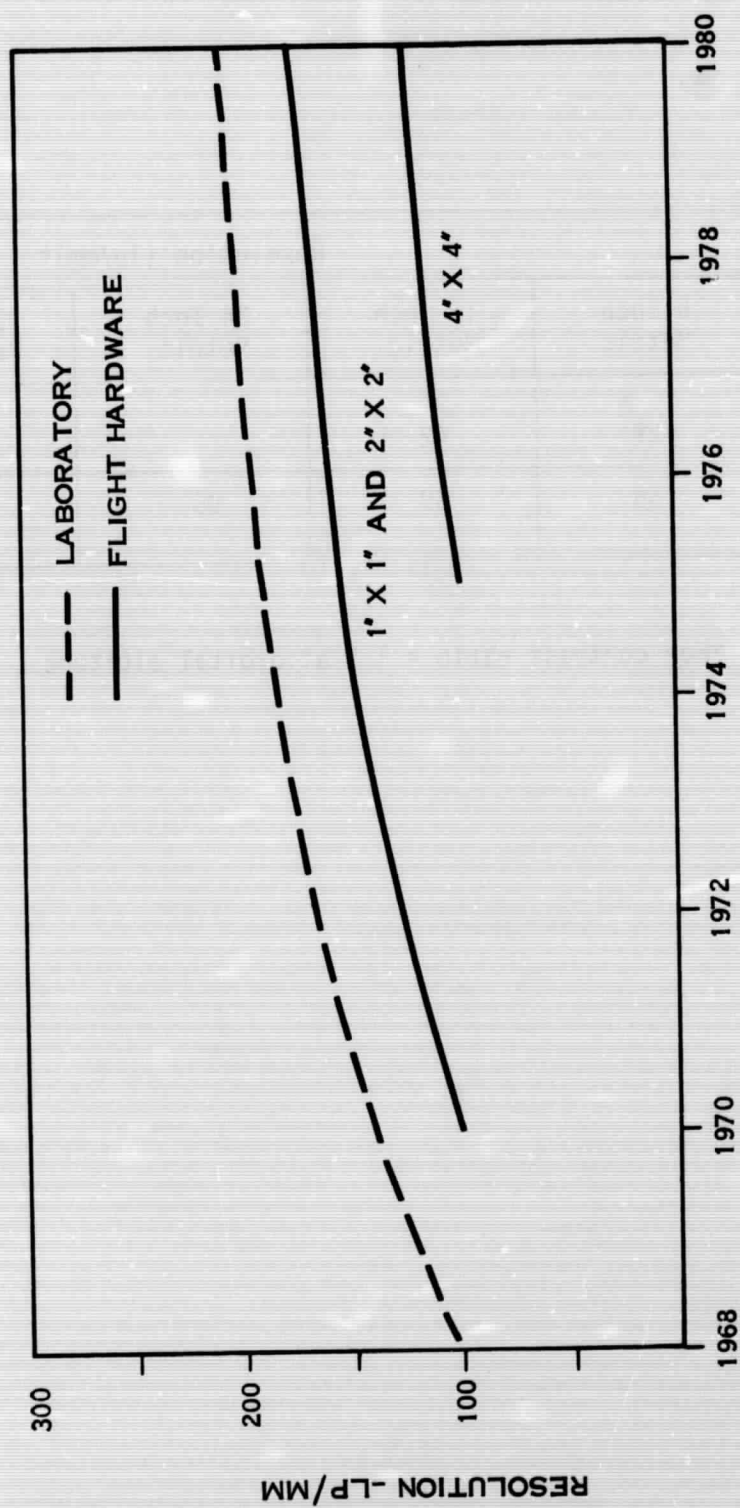


Figure 3-8. Future Trends in TV Camera Resolution

Table 3-6. Comparison of Resolution - 1970 and 1975 Photocameras

	Resolution (lp/mm)*				
	6 Inch Metric	12 Inch Metric	24 Inch Metric	24 Inch Panoramic	72 Inch
1970	29	42		72	
1975	56	69	90	120	120

*For contrast ratio = 1.3 at orbital altitude

Table 3-7. Comparison of Near Future (1975) Photocameras and TV Cameras

	DIMENSION OF RECORDING SURFACE (IN.)	LIMITING RESOLUTION (LP/MM) *		TOTAL LINE PAIRS	
		AT 1.3 1 CONTRAST	AT 1.15 1 CONTRAST	AT 1.3 11 CONTRAST	AT 1.15 1 CONTRAST
PHOTOCAMERA	9 X 9	90	35	20,600	8000
VIDICON	4 X 4	88	57	8,950	5800

* INCLUDES LENS (50% DIFFRACTION LIMIT) AND FILM OR VIDICON CHARACTERISTICS

The feasibility of obtaining metric quality with TV depends on availability of sweep linearity of the order of 0.002 percent, which represents the present accuracy of metric photocameras (5-micron positional accuracy on 9-inch film). By using analog deflection circuits, sweep linearity of 1 percent is currently achievable. As illustrated by Figure 3-9, slow improvement is expected through further research on the causes of nonlinearity.

Recent laboratory developments in digital drivers for flying spot scanners show a linearity of 0.025 percent. It is expected that by the mid-1970's the techniques now used to position the beam of electrons in the flying spot scanner can be applied to the slower electrons used in the readout of the vidicon target, but linearity below 0.01 percent is not feasible. The alternative, which should be studied, may be extensive data processing based on fiducial marks placed on the imaging surface of the vidicon. For the 1975 time frame, TV systems were not considered to have metric capability but may approach metric quality in the early '80's.

In the preceding analysis only the resolution characteristics of the vidicon (including its lens) and the camera (including its lens) plus film were discussed. Other system elements may effect the quality of the final hard copy, which have not been discussed; some of these are shown in Figure 3-10. Radiation effects can change the characteristics of the film negative while stored aboard the spacecraft, and magnetic field can affect the imagery received by the vidicon.

3.2.2.1.3 Radiometers

An examination of experiment types applicable for the Space Station indicates three types of requirements for optical radiometry. The first calls for radiometry to perform functions auxiliary to imagery in the visible band. This

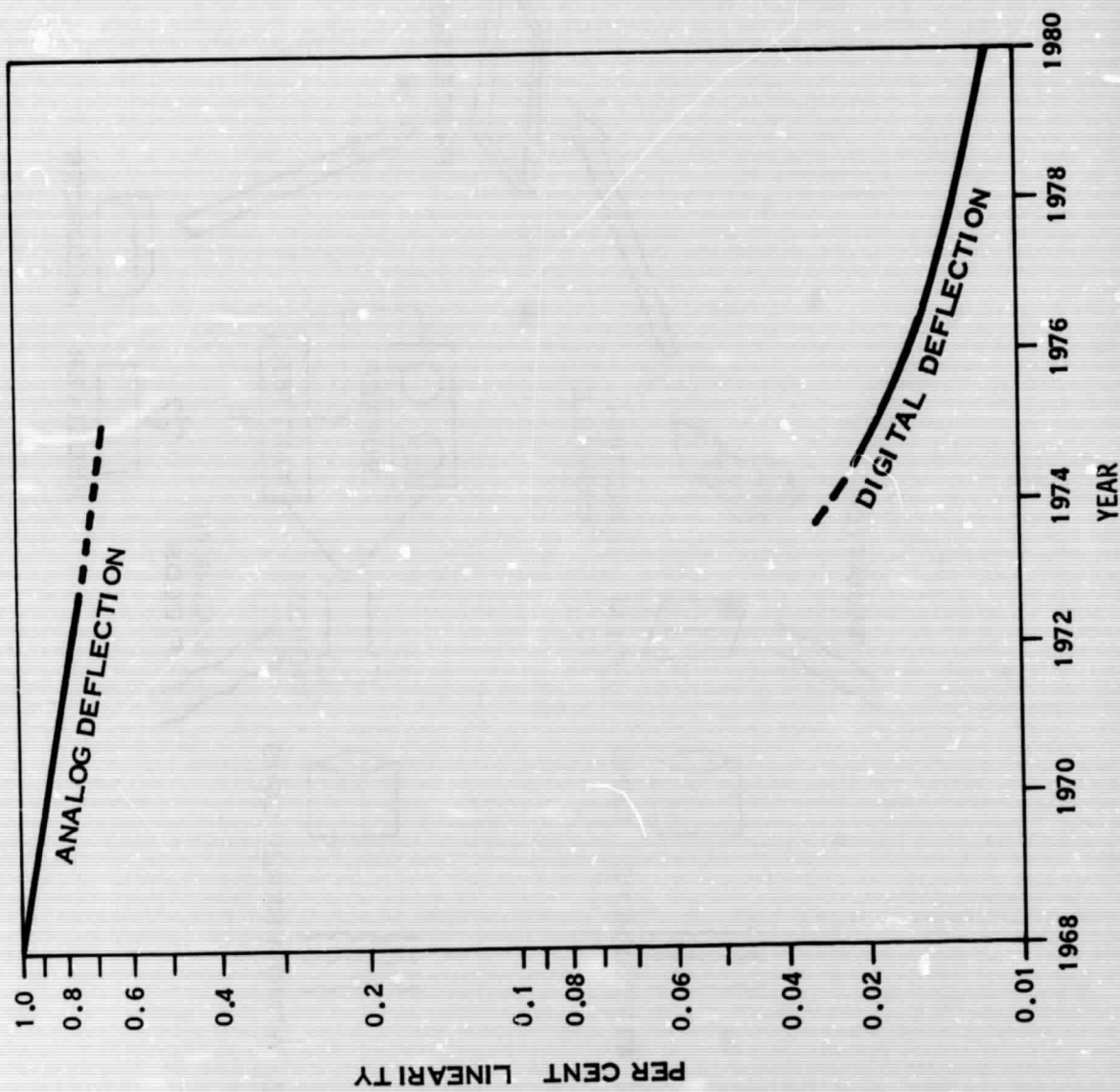


Figure 3-9. Future Trends in Sweep Linearity of TV Cameras

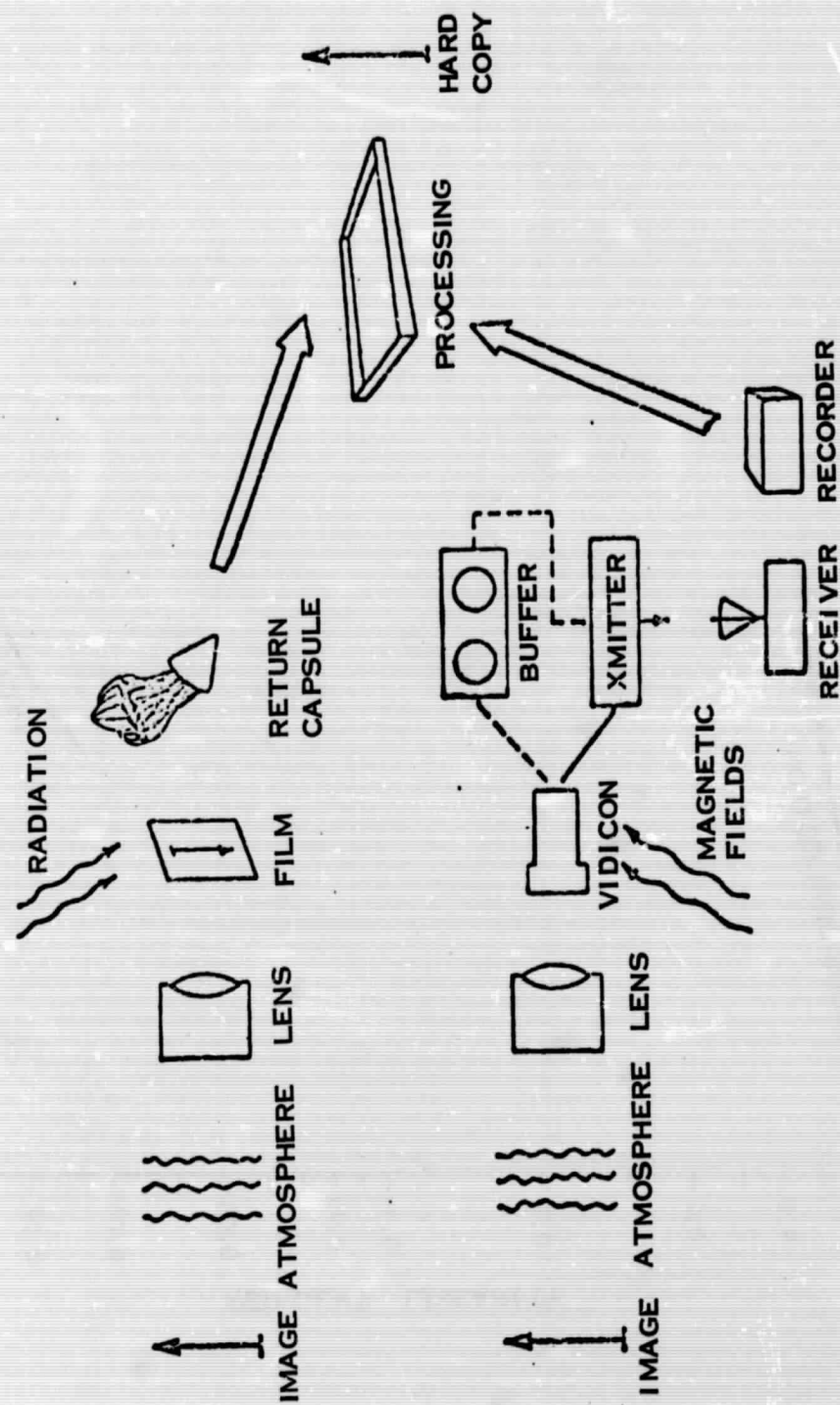


Figure 3-10. Imagery Collection and Retrieval System

supplies the user with a thermal picture of the area taken with optical imager. The wavelengths at which the information is taken indicated as 3.4 to 4.2 microns and 8 to 11 microns, representing the windows in the atmosphere through which thermal information can be received above the atmosphere.

The second type of task calls for the examination of the total heat budget, ranging from 2.4 to 30 microns; this is not dependent on the atmospheric windows because it observes the whole atmosphere. The third type of task calls for multispectral examination of the visible and infrared portion of the spectrum. Presently only agricultural users have requested multispectral capability. However, it is seen as a new tool to complement visible band imagery for many earth survey applications.

Radiometry aerial coverage requirements, which are comparable to optical imagery, may vary from 10 to many hundreds of miles in width. Unlike aerial coverage, resolution requirements for radiometry are about 10 times poorer than for optical imagery. Spatial resolution requirements range from about 50 to 10,000 feet. For most earth survey tasks, resolutions from 1,000 to as little as 50 feet are desired. For atmospheric tasks, grosser resolution requirements are acceptable.

Of the several radiometers available, three Medium Resolution Infrared Radiometer (MRIR), High Resolution Infrared Radiometer (HRIR), and the 3-channel radiometer meet the spectral requirements for area coverage. The swath width for these three was superimposed on the coverage requirements in Figure 3-11. The sensor swath width shown does not reflect a change in the basic sensor design as specified in the sensor bank. Rather, a hypothetical adjustment in the scan angle was made to ensure contiguity of scan coverage for operation at 250 and 500

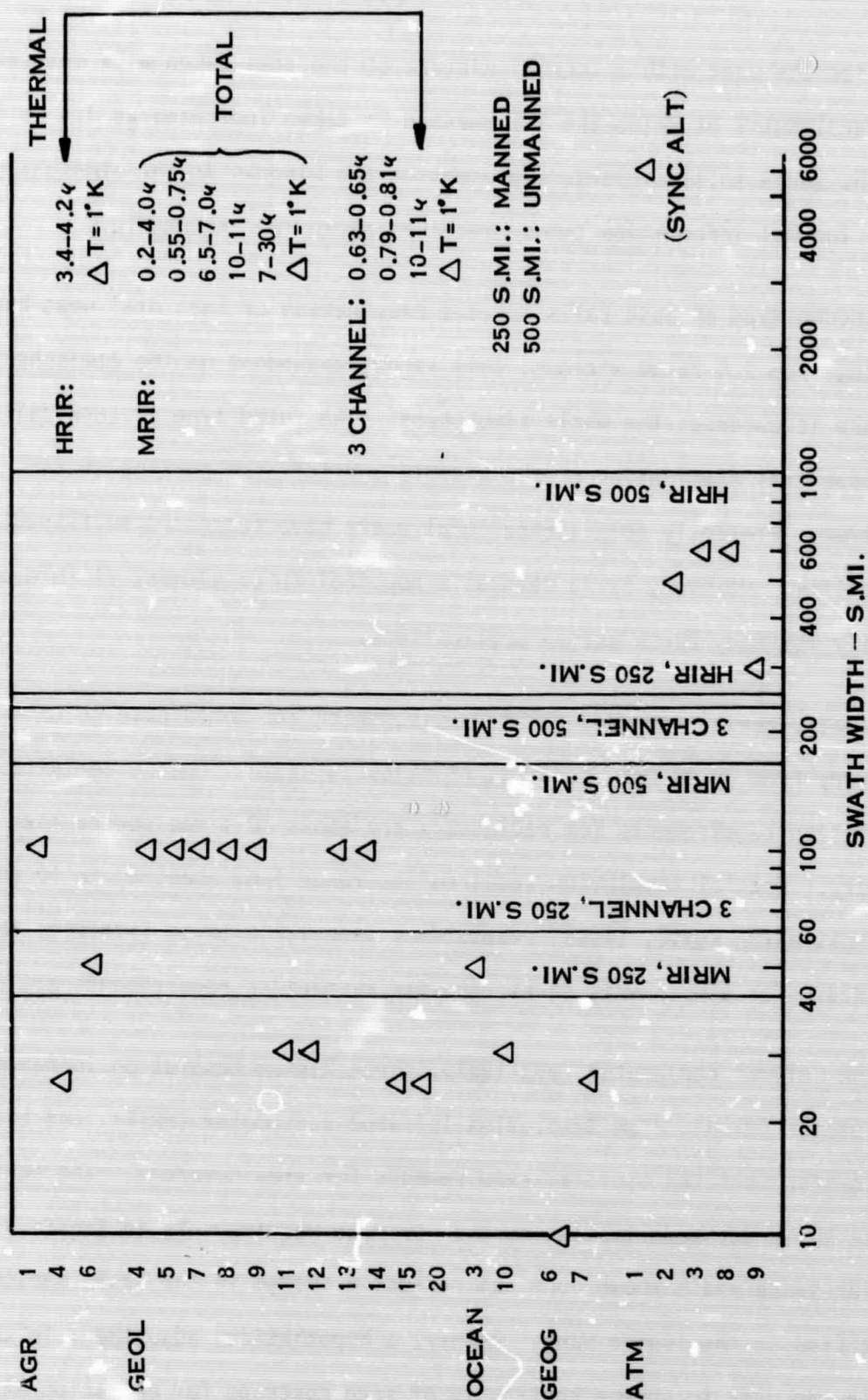


Figure 3-11. Optical Radiometry: Coverage Requirements -VS- Current (1970) Capabilities

statute mile altitudes. This adjustment compensated for the HRIR and MRIR radiometers design for use at 600-nautical mile altitude and the 3-channel radiometer design for 125-nautical mile altitude.

It is apparent that the swath width capability of these sensors is much greater than many of the tasks require and reflects their design primarily for use in the atmospheric sciences. Only the MRIR and 3-channel radiometers operating at low altitudes can meet the user resolution requirements, which range from 1,000 feet down to 100 feet for tasks requiring thermal imagery.

The key to improvements is determined by the equation relating basic detectivity to the characteristics of the detector and the target. In the thermal region (from 8 to 13.5 microns), for example, the relationship for the noise Equivalent Temperature ($S/N = 1$)* is:

$$NE\Delta T \cong E_f \frac{\sqrt{A_d} \sqrt{\Delta f_n}}{D^* \lambda_c} \frac{\lambda_c}{\Delta E} \frac{T^2}{D^2} \left[\frac{h}{G} \right]^2$$

Where:

E_f = Efficiency factor

T = Absolute temperature ($^{\circ}K$)

D = Aperture diameter

h = Altitude

G = Ground resolution length

Δf_n = Bandwidth of amplified signal

λ_c = Cut off wavelength

λ_2 = Blackbody radiation

λ_1 = Emitter wavelength

D^* = Specific detectivity

A_d = Detector area

*Derived from Equation 15, P. 123, Vol III: Univ. of Michigan, Willow Run Laboratories: "Peaceful Uses of Earth Observation Spacecraft". Feb. 1966.

This equation shows major radiometer performance improvements are achievable by developments along three lines: larger collecting apertures, lower aperture losses, and improved detectivity.

Current sensors use collector apertures that vary from 3 to 8 inches in diameter. It is feasible to extend collector sizes to at least 38 inches, representative of a collector already under development.

Losses occur in radiometer systems because of multiple mirror and optical surfaces through which energy must pass. General mirror efficiencies are already high (on the order of 0.95); however, multiple reflections may reduce this efficiency in some cases to about 0.6. Other losses include losses in the prism, losses through the chopper that converts the DC signals to AC, and losses in the preamplifier and other electronic circuits. These losses tend to reduce the overall efficiency of current instruments to values ranging from 15 to 40 percent. Conservative estimates place the overall efficiency improvement factor achievable by 1975 at 1.5 and 1.8 by 1980.

Cooling the detectors will provide substantial improvement in radiometer sensitivity. Present Nimbus and TIROS sensors are not cryogenically cooled; they are cooled to approximately 200°K for periods of at least one year. An improvement in sensitivity of 10.1 is expected with such cooling.

Two other areas of improvement are indicated in the radiometer equation. One is the reduction of detector area, which should improve the signal-to-noise ratio; the other is improvement in detector frequency response. By 1975 a conservative factor of two is estimated in the improvement through these changes.

Theoretically, these improvements could be applied to all radiometers. However, instead of using extrapolated technology to optimize many instruments, a more desirable approach is to consider a single instrument covering all bands of interest at the resolutions required, incorporating all these advances.

The Infrared Laboratory of the University of Michigan has been concerned with the design of such a single multipurpose instrument. Considering the expected technological advances and the users' requirements, they have proposed an advanced multispectral radiometer for the Apollo Applications Program. This concept is used to project radiometer capabilities for 1975 to 1980 and is shown in Figure 3-12.

The proposed system, which covers the spectral range from 0.33 to 13.5 microns, is extendable by additional detectors to 30 microns. The current instrument has 29 spectral bands, each with its own detector, of which five types work in their most effective wavelength regimes.

The design sensitivity is 0.01 to 0.02 noise equivalent spectral reflectance difference $(NE\Delta P)_{s\lambda}$ in the region from 0.33 to 1.06 microns where 13 channels are used. This sensitivity is achieved using sensitive photomultipliers working with strong, reflected sunlight signals expected in this spectral region. Sensitivity is obtained at the same time, achieving spectral resolving power $\frac{\lambda}{\Delta\lambda}$ of from 6 to 20; based on anticipated target spectral characteristics, this should be an adequate and practical goal.

The spectral region from 1.06 to 5.0 microns, measured by detectors cooled to 77° for improved performance, is divided into only five channels because of the weak radiance of targets in this region and the dispersion characteristic of the material in the prism. Sensitivity varies from an NE ΔP of 0.05 at 3.0 microns. The noise equivalent temperature difference (NE ΔT) is less than

CHARACTERISTICS

SPECTRAL COVERAGE: 0.33 - 13.5 μ ; EXTENDABLE TO 30 μ
 SPECTRAL BANDS: 29; EXTENDABLE FOR ADDITIONAL COVERAGE
 COLLECTOR: MIRROR; 6", f4; EXTENDABLE TO 38"
 ΔT : 0.1 TO 0.5° K ($\lambda > 3\mu$)
 COOLING: LIQUID He, N
 SPECTRAL RESOLUTION:

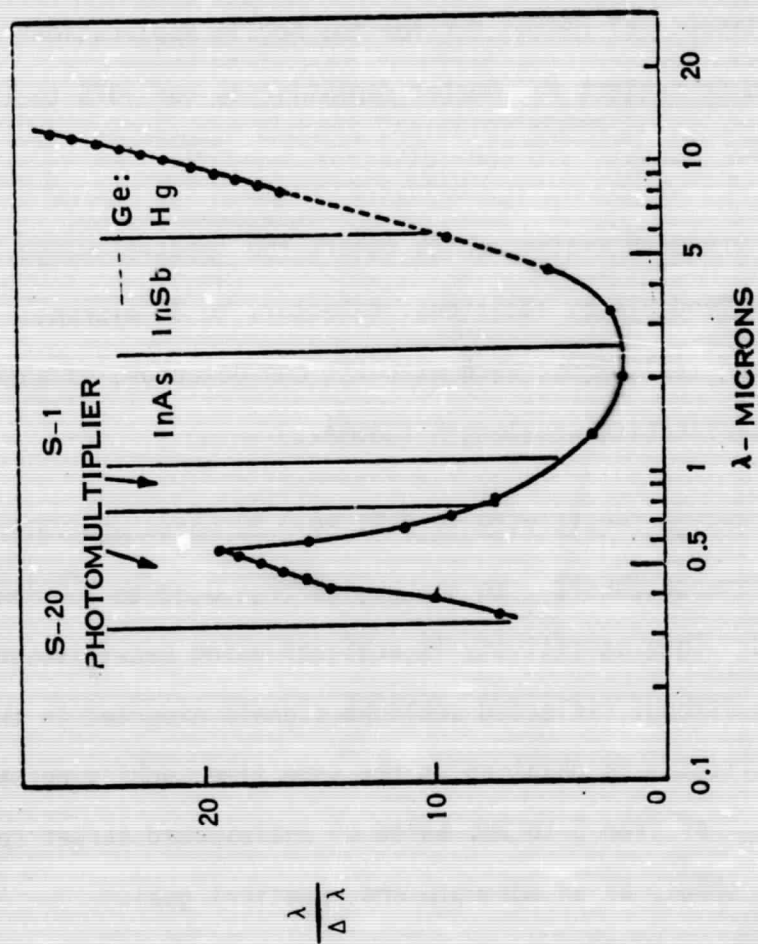


Figure 3-12. Advanced Multi-Band Radiometer Concept (1975-1980)

0.7°K between 2.8 and 3.2 microns and decreases to 0.1°K at 5 microns.

In the thermal spectral region, the detectors are cooled to 4°K for increased sensitivity. The NEΔT increases from 0.3°K at 8 microns to 3.0°K at 13.5 microns. This region is divided into 11 channels, with spectral resolution $\frac{\lambda}{\Delta\lambda}$ increasing from 16 to 27. These characteristics are the best match of state-of-the-art capability to multispectral signature sensing requirements, obtained with a 6-inch diameter collector, forming 29 identical instantaneous fields of view.

3.2.2.1.4 Spectrometers

A number of tasks in Oceanography and Atmospheric Sciences specify a requirement for spectrometric information. These projected requirements for 1975 are compared with current sensor capability in Table 3-8. The desired ground resolution for spectrometry is quite gross, being measured in miles. Earth resource experiments have also expressed requirements for spectrometry. The potential for spectrometry in the earth resource area appears extremely great, and a wider use of this technique is anticipated in the late 1970's and early 1980's. The spectrum requirement for each resource lies primarily in the 0.4 to 14 range.

The Absorption Spectrometer does not meet resolution requirements at either 250- or 500-mile altitude; the IR Interferometer Spectrometer meets some of the user requirements at both altitudes. The Temperature Profile Spectrometer does not meet any requirements of the tasks for which it is required.

The resolution requirements for the Earth Survey Tasks were indicated in the chart as indeterminate because of the paucity of information available. However, the capability of the Filter Wheel Spectrometer (shown as 0.9 to 1.8 miles) is

Table 3-8. Spectrometry; Requirements -VS- Current (1970) Capabilities

REQUIREMENTS				CAPABILITIES		
TASK	PURPOSE	SPECTRAL BAND DESIRED, (μ)	GROUND RESOLUTION DESIRED (s mi)	APPLICABLE SPECTROMETER	GROUND RESOLUTION (s mi)	RESOLVING POWER $\frac{\lambda}{\Delta\lambda}$
					250	500
OCEAN-3	FISH LOCATION	0.3-0.6	1	ABSORPTION	4.4	500
ATM-10	AIR POLLUTION	0.28-0.33; 0.6-0.75	1		8.8	
ATM-6	ATMOSPHERIC HUMIDITY	SELECTED INTERVALS WITHIN 3.5-16	4-30	IR INTERFEROMETER	13.0	550 (at 6μ)
GEOL-17	ATMOSPHERIC HUMIDITY	SELECTED INTERVALS WITHIN 3.5-16	4		26.0	
ATM-4	ATMOSPHERIC TEMPERATURE	10-11 AND SELECTED INTERVALS AROUND 15	1-20	TEMPERATURE PROFILE	54.5	360 (at 5μ)
	ATMOSPHERIC TEMPERATURE	4-5	1-20		109	
ATM-7	OZONE DISTRIBUTION	0.2-0.32	3-25	BACKSCATTER UV	0.17	300
EARTH SURVEY TASKS	DETERMINE CHARACTERISTIC SIGNATURES	0.35-13.0	INDETERMINATE	FILTER	0.9	100

considered adequate for initial determinations of characteristic signatures in earth survey tasks.

All sensors listed are man attended and are not designed for automated operation. A transition from manual to automated operations is required in the 1980 time frame to allow more extensive utilization of spectrometry. For instance, remote experiment module utilization requires automated sensors.

Spectrometers marginally meet user requirements for resolution in their selected spectral bands. At the present time there are no firm requirements for resolving power for the various tasks; the capabilities shown are considered adequate for initial operations.

Larger apertures and improved detectivity through the use of cryogenic cooling should increase the detection capability. For earth survey tasks the specific requirements of spectrometry are not well defined; however, there will be a requirement for improved spectral resolution, which will partially be met by improvements in basic energy collection and detection.

Based only on increase in collector size to 38 inches, improvements of about 10 to 1 in spectrometer spatial resolution capabilities are estimated, compared to current Absorption, Interferometer, Temperature Profile, and Filter Wheel Spectrometers. For earth survey tasks, extension of spectral coverage into the visible band (0.45 to 0.7 microns) is desirable; the Absorption Spectrometer is readily adaptable to this range.

It would be desirable to consider the feasibility of incorporating many of the spectrometer capabilities into a single instrument. A development study is required to determine the problems associated with this approach.

3.2.2.1.5 Summary

- o Predicted 1975 Resolution Requirements - 0.07 milliradian (100 feet at 250 N.M. altitude). Marginally consistent with present equipment capability.
- o Resolution requirements may become more stringent by 1985 - 0.007 milliradian (10 feet at 250 N.M. altitude). Camera and vidicon development is required to meet these requirements.
- o Vidicons can be improved from present laboratory status of 100 line pairs per millimeter (0.045 mr resolution) to 150 line pairs per millimeter by 1975 (assumes a 2-inch x 2-inch format). The probability of a 9-inch x 9-inch format by 1980 is 50 percent with 0.2 radians field of view. Its resolution will be approximately 0.006 milliradian which is consistent with projected requirements.
- o Radiometer resolution capabilities are greater than 2,000 feet. Improved characteristics are desirable for 1975, and major improvements are desirable for 1985.
- o Spectrometers marginally meet spectral resolution requirements and fail to meet ground resolution requirements for 1975.

3.2.2.2 Film

- o Grain resolution of approximately 300°A presents no restraints for Space Station application through 1985.
- o Two Space Station applications (see Table 3-9) - photography and data storage. Extensive use of photography is foreseen in early Space Station phases. Associated with photography is the manual interpretation problem. As automated analysis techniques are developed, the use of photography is expected to decrease 70% by 1985.
- o Problems associated with film:
 - Controlled environment: for best results, 32°-75°F and 50% relative humidity or less.
 - Processing: onboard - special precautions required to avoid release of contaminants in the Space Station. A dry, rapid access process (Kodak Bimat) exists which provides a quick look. After three days, image degrades if film is not washed. One solution is to return the unprocessed film to earth. Adequate radiation protection must be provided. Desirable to store film after exposure at less than 32°F.
- o Photography

Sensitivity, hue and gray range are adequate for foreseen Space Station requirements through 1985 for conventionally developed films. For dry processed films, contrast range and image spot size appears inadequate for certain earth resource, atmosphere and astronomy experiments.

Typical film characteristics are:

Gray range:	200 shades
Hue:	20,000 hues
Spectrum (reflected):	Ultraviolet through near infrared (0.3 - 1.2 microns)

Table 3-9. Film

o Space Station application	o Manual interpretation of photos (3000/day) presents overwhelming workload. Automated analysis techniques required.
- Photography	
- Data storage	
o Film characteristics	o Adequate for Space Station requirements
- Gray Range: 200 shades	
- Hue: 200,000 hues	
- Spectrum (reflected): 0.3-1.2 microns	
- 300°A grain resolution (hi resolution)	
o Processing	o Special precautions required for wet process to avoid release of contaminants. Dry process image degrades if not washed. Technology advances required in dry processing. Storage environment must be controlled.
- Wet	
- Dry	

3.2.2.2.1 Film Technology Comments

Characteristics of conventional wet processed film are considered adequate for the Space Station application through 1985. Onboard processing of this film will be minimized because of the problems associated with protecting the Space Station's atmosphere from toxic fumes. The problem is more pronounced with colored film because of the more complex processing.

Current dry process films are indicative of the technology suitable for Space Station application. Kodak has developed a dry-processed, transfer film called BIMAT and two dry silver process films, Number 1877 and an experimental version.

Because of their thin emulsions, most of the BIMAT processing systems use the RAR films (Rapid Access Recording). Several are available for exposure in the visible and near infrared regions. Not all Kodak films can be processed by the BIMAT process. For example, Kodak professional film: some color processing (first step only) has been done in special applications at White Sands. Until recently, such systems have not been available commercially being all for military development (35,000-40,000 rolls per year in Vietnam) and special applications (Lunar Orbiter).

The main advantage of BIMAT is for those applications where a "quick look" capability is needed and there is no water or electricity available. The film should be washed and dried later for retention using conventional equipment. Disadvantages include the fact that BIMAT film is more expensive than regular film, special processing is required, and it must be washed and dried for use as a permanent record.

BIMAT film is shipped in sealed and refrigerated cartons directly to the customer. Shelf life is six months at 40°F and three weeks at 72°F (recommend not freezing). When the protective seal is broken, BIMAT film should be used within 1 to 1 1/2 hours. Some of the processors have special pads which protect the film for a day or so. The problems are evaporation and interaction with oxygen.

The development film is as good (resolution and contrast) as if it were developed conventionally provided it is kept at normal temperature for the recommended time (10 minutes). You can have the film laminated for up to three days without degradation. Figure 3-13 shows vendor curves for Type 1877 development rate. An experimental P11 Phosphor model is shown in Figure 3-14.

The Mark Systems processing equipment brackets the various films from 8mm up to 9 1/2 inch wide rolls in 15 to 1000 feet lengths. One model (suitcase size) is hand cranked while others are motorized. The speeds vary from 25 feet per minute to 2000 feet per hour for laminating speeds. The Model 350 is a floor model for handling 70mm, 5 inch and 9 1/2 inch film at the higher speed and is "MIL-SPEC" for ship, trailer, etc.

BIMAT has also been used in two special projects: system for the AEC where processing was to be done "right away" because of the radiation hazard, and the Air Force at Wright-Patterson Air Force Base for evaluation of airborne use. Here, copy is produced in 15 seconds (positive only) at 120°F. The negative is not developed completely. The equipment is larger and more expensive. The film used is S0185D. This system built by HRB Singer and Kodak is under evaluation.

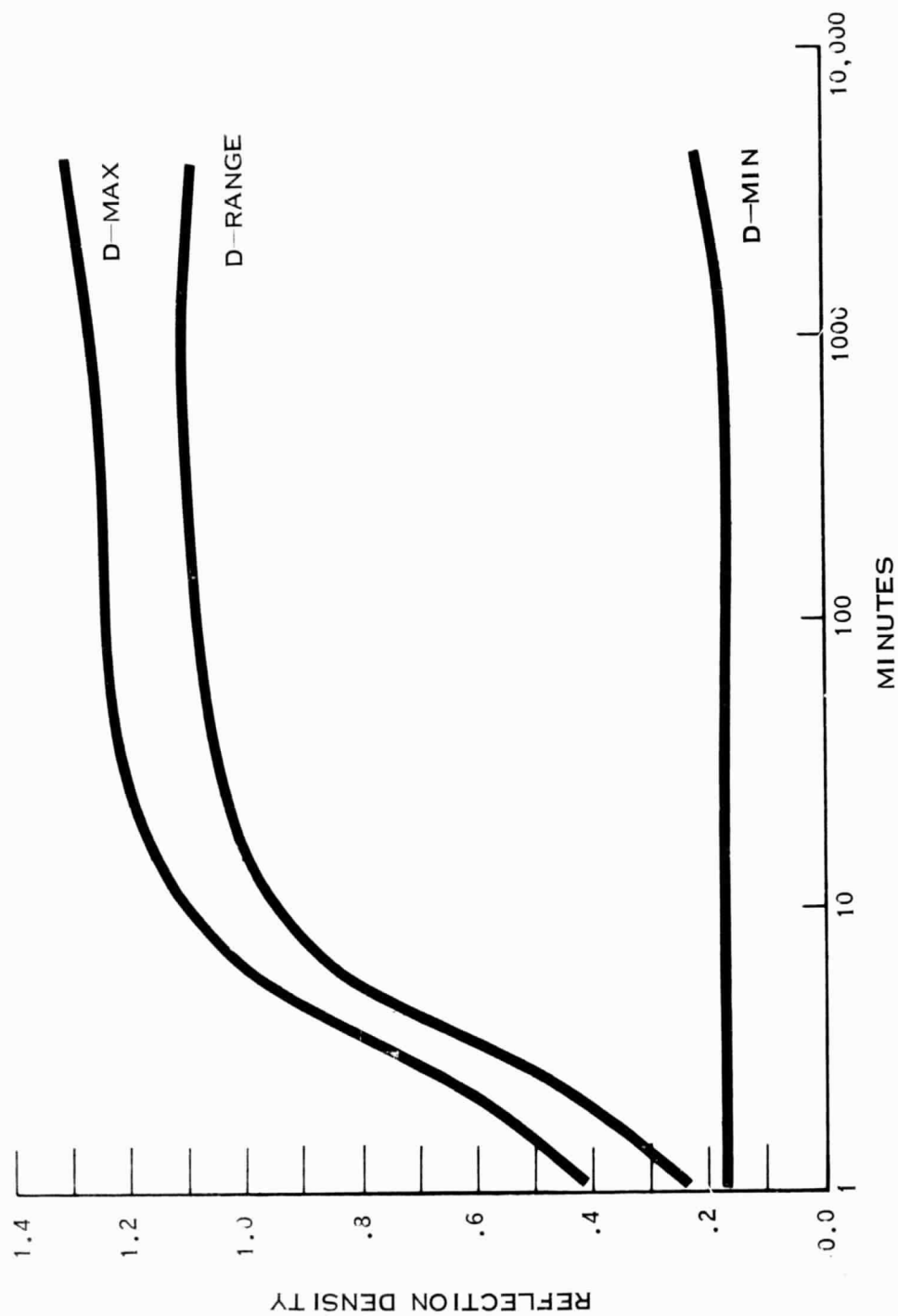


Figure 3-13. K-1877 Photo Development Rate 250 Foot-Candles Daylight Fluorescent

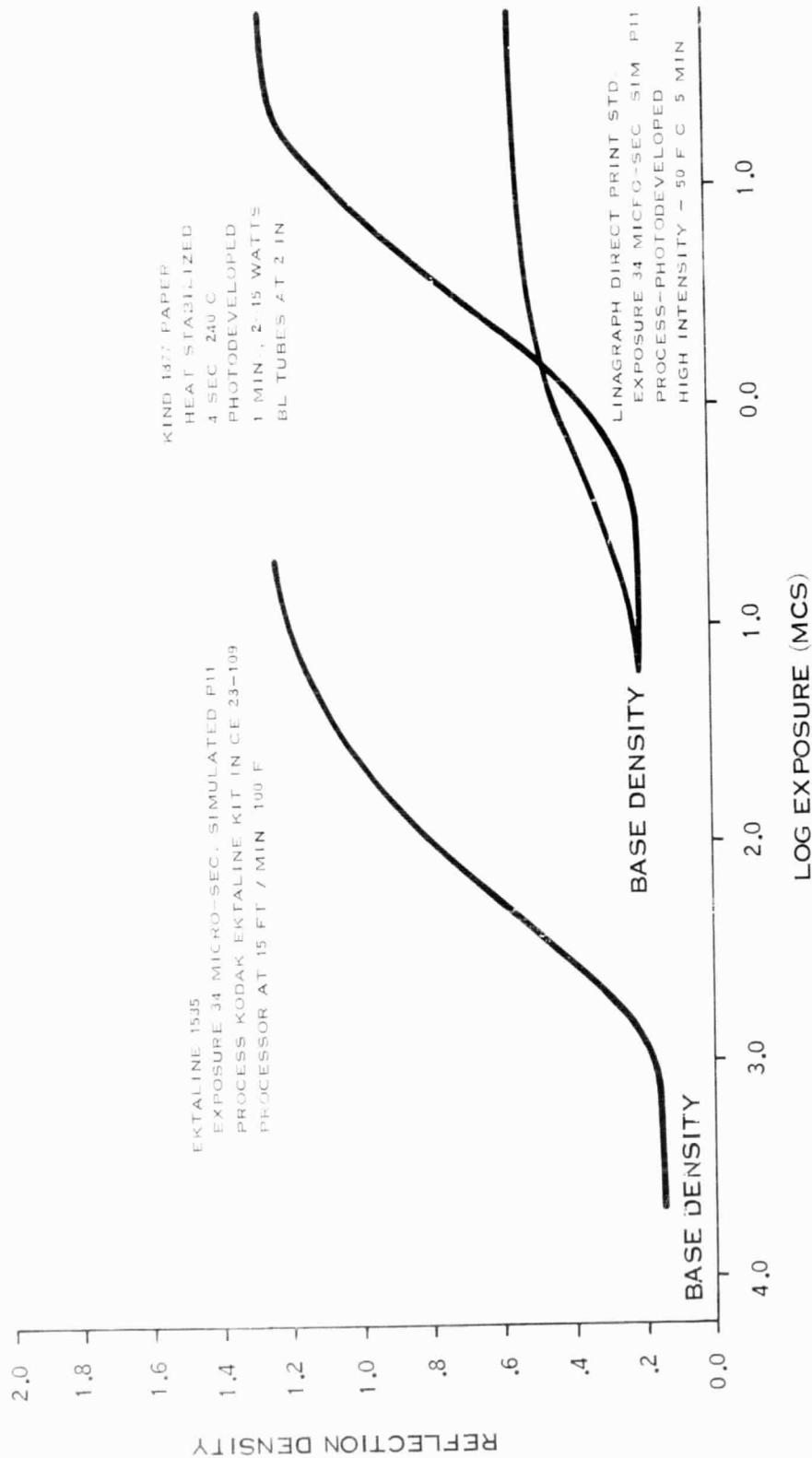


Figure 3-14. Simulated P11 Phosphor Characteristic Curves

3.2.2.2.2 Data Storage

The Space Station will be generating data at an equivalent of 10^{12} bits/day in 1975 and 10^{14} bits/day in 1985. Some of this data will be in the form of photography and the remainder as stored digital data. Photography will be utilized extensively in the 1975 time frame but minimally by 1985 because it will be replaced by automatic analysis techniques (see Table 3-10 and Figure 3-15). Five techniques exist for the storage of bulk data:

- o Magnetic tape
- o Film recording by electron beam (or other energy source)
- o Thin film - Laser
- o Thin film - Ovonic
- o Holograms.

Of these techniques, holograms probably have the greatest potential for high density storage but is the least developed. A brief comparison of bit densities and data rates of the techniques obtainable in the laboratory or limited production are:

<u>System Type</u>	<u>Density (bits/in²)</u>	<u>Recording Rate (bits/sec)</u>	<u>Transfer or Read Rate (bits/sec)</u>
Film (Cypress)	2.5×10^6	0.5×10^6	2.5×10^6
Tape - present	5.0×10^6	$2-20 \times 10^6$	$2-20 \times 10^6$
Holographic - present	10^6	?	10^7 Range
Laser recording	6.0×10^7	4.0×10^6	4.0×10^6
Ovonic thin film	1.5×10^6	10^6	5.0×10^7

Table 3-10. Key Issue - Bulk Data Storage

- o Storage capacity and recording rates should be adequate to store 10^{10} bits/day (1975) and 10^{12} bits (1985).
- o Present (1969) storage capabilities (laboratory) - flight available for 1975 by concentrated development:

	<u>Tape</u>	<u>Film</u>	<u>Laser-Thin Film</u>
Density (Bits/In ²)	5×10^6	2.5×10^6	2×10^7
Recording Rate (Bits/Sec)	$2-20 \times 10^6$	0.5×10^6	?

- o This means (requirements as follows with 1975 capability):

	Storage Volume (FT ³)*						Recording Rate (MHz)		
	1 Day		30 Days		1975	1985		1975	1985
	1975	1985	1975	1985					
Storage Medium									
Tape Film Thin Film	0.02	2	0.6	60	0.1	10	0.1	10	
	0.04	4	1.2	120					
	0.01	1	0.3	30					

*Assumes 0.01 inch thickness in each case and a factor of two allocation for storage hardware such as tape, film reels, etc.

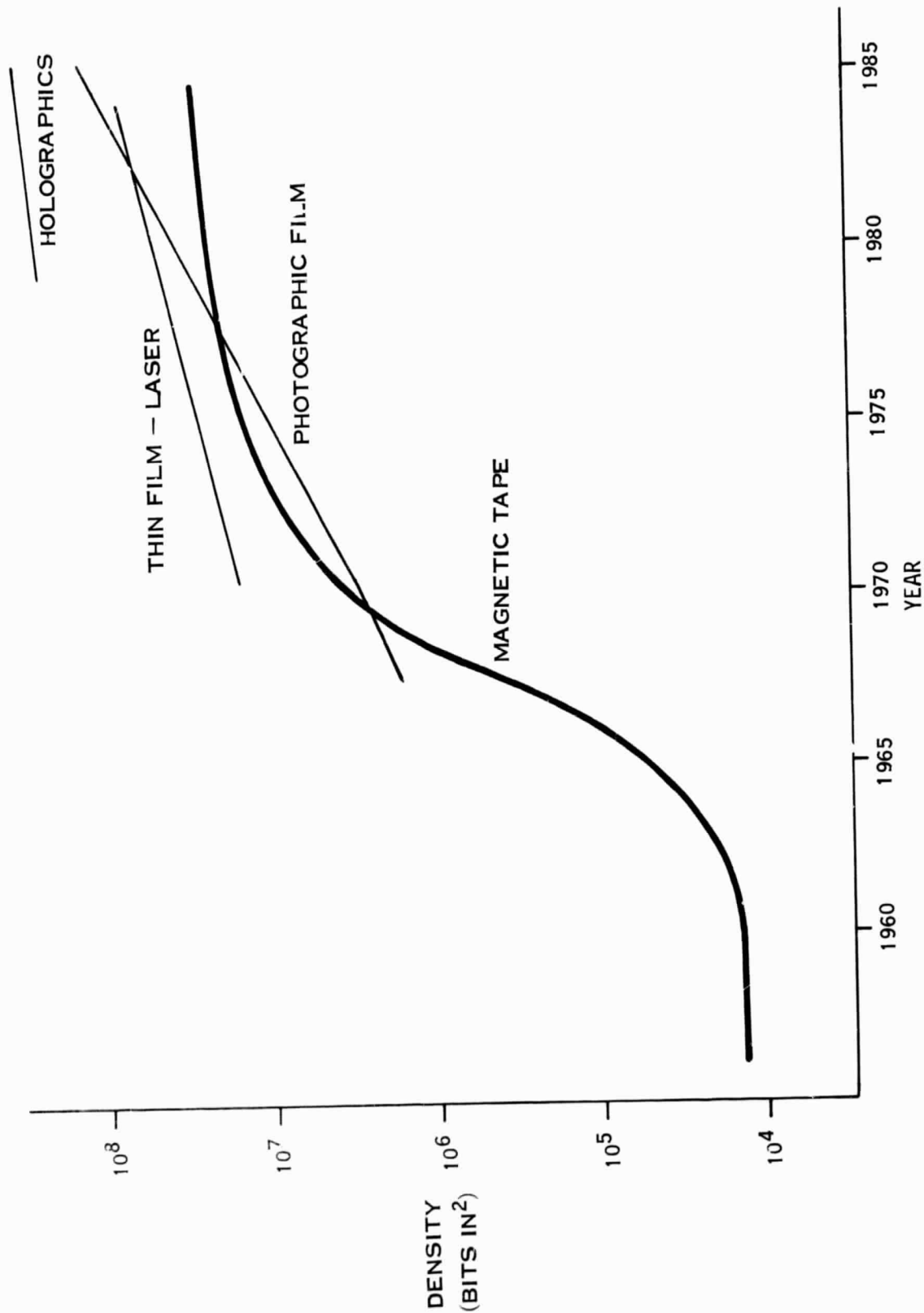


Figure 3-15. Data Storage Density Trends

3.2.2.2.3 Film Storage

Bulk data storage densities on film of 2.5×10^6 bits/square inch have been obtained in the IBM System/360 Photo Digital System. The data rate limitation of the system is 0.5×10^6 bits/second corresponding to 4.3×10^{10} bits for a 24-hour period. This capability is compatible with each of the medium sized astronomy and earth resources experiment packages whose requirements are 1.2×10^{10} and 5.8×10^{10} bits/second respectively.

The recording section appears most suitable for installation in the Space Station. It could be housed in a 2 x 4 foot section of standard rack depth. In this case, the film with the latent image would be returned to earth for developing and analysis. For one day's recording at the maximum rate, approximately 1.5×10^3 feet of film would be required using a strip width of 1.4 inches housing a one inch equivalent width of recorded information.

The Photo Digital System is in laboratory production and features a trillion bit data storage system. Its general characteristics are:

- o Data is recorded on a silver halide emulsion coated on a polyester material called a film chip. Approximate size is 1.4 inch x 2.7 inch x 0.007 inch. Each chip nominally contains 5×10^6 data bits.
- o Electron beam recording has quality comparable to that found in electron microscopes. Nominal beam size is 8 microns in diameter.
- o Basic output is 2.5 megabits/second.
- o Unit has built-in diagnostics.
- o Front end limits the system to a maximum recording rate of 0.5×10^6 bits/second. The restraint occurs in the energy density of electron beam and the film sensitivity.

Major rack mounted components of the system are:

- o Cell file and control processor
- o Reader
- o Recorder
- o Data controller
- o Printer - keyboard.

3.2.2.2.4 Tape

High density tape storage has been developed by IBM. Bit density is 20,000 bits per inch per track or 5×10^6 bits per inch for the present design assuming the equivalence of one flux reversal per bit. In the present design, 250 feet of tape occupying 1/2 inch thickness on a nominal 4 inch diameter reel can store roughly the daily output of a medium sized astronomy package (1.5×10^{10} bits). Unit reliability and data degradation as a function of storage time is essentially unknown.

For Space Station application, the unit could be modified easily to permit cartridge loading. The nominal tape speed is 1000 inches per second corresponding to data transfer rates of 20 megabits per second. For slower recording rates, it is felt that the tape may be slowed to 100 inches per second without degrading bit density.

3.2.2.2.5 Holographics

Techniques utilizing holograms for data storage are essentially undeveloped. A photographic emulsion or a metallic thin film is used to record the holograms. These holograms, when illuminated by a laser beam, produce an image at a point in space comprised of interference patterns. The interference patterns are

detected by an array resulting in a direct digital readout. The capacity of such a memory is presently limited by the detector array to a density of $10^5 - 10^6$ bits/in². The ultimate density is quoted to be 3×10^8 bits per square inch.* A major problem facing holographic storage techniques in Space Station applications is the requirement for a large computing capacity to generate the holograms.

3.2.2.2.6 Laser - Thin Film Recording

A laser recording unit has been developed by the Precision Instrument Company of Palo Alto, California. This unit (with densities of 6×10^7 bits per square inch) appears potentially applicable for the Space Station. The laser is used to encode data on a metallic thin film by vaporizing minute holes in the metal.

*H. R. Vilkomerson, R. S. Mezrich and D. I. Bostwick, "Holographic Read-Only Memories Accessed by Light Emitting Diodes," 1968 Fall Joint Computer Conference.

3.2.2.3 Controls and Displays

In discussing control and display technology for the 1975-1985 Space Station, (see Table 3-11 and Figure 3-16) a baseline of present technology is established.

3.2.2.3.1 Control Panel Components - General

The various components available for use on control panels are as follows:

- o Nonilluminated switches
- o Illuminated indicator switches
- o Projection-cue-indicator switches
- o Message indicators
- o Readouts
- o Meters
- o Dials
- o Control knobs
- o Potentiometers
- o Resolvers
- o Timing indicators
- o CRT hand controls
- o Keyboards
- o CRT panel displays.

All of these components are presently used on avionic or astrionic control panels. They are either totally visible at the front of the panel or are protruding through the rear of the panel. The components are interfaced by digital and/or analog means to the equipment they control.

Table 3-11. Controls and Displays

- o Reduced operator complexity yet maintain a high degree of function complexity
- o Interaction of remote controls/displays with the central crew station controls and displays
- o Automated real-time displays with orders of priorities.

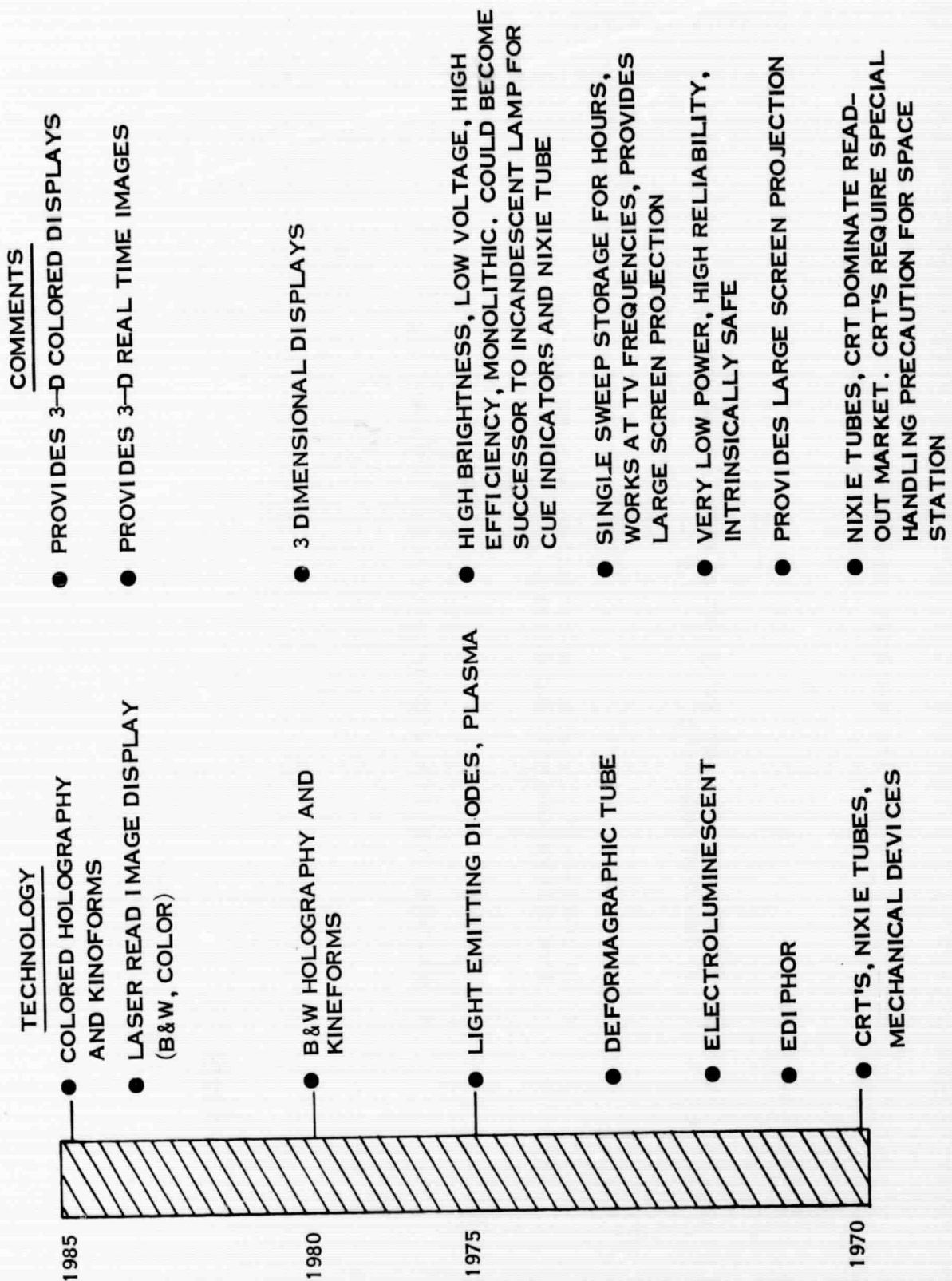


Figure 3-16. Display Technology

3.2.2.3.2 Nonilluminated Switches

Table 3-12 illustrates the many types of nonilluminated switches that can be mounted on control panels. These switches are not illuminated but could have their position (such as "ON" and "OFF") marked as part of the switch, but some panel marking and lighting is usual. The switches come in various sizes, number of positions, and poles. The current rating is as high as six amperes at 125. Table 3-12 also indicates application of these switches to digital and analog interface and rates them for use through 1975.

3.2.2.3.3 Illuminated Indicator Switches

Illuminated indicator switches are gaining more prominence in panel application. Advantages of these switches include:

- o Split screen
- o Multiple color for cueing and verification
- o Engraved legends as part of switch
- o Illuminated legends
- o Low voltage logic for lamp drive
- o Longer life incandescents
- o Flush mounted switches
- o Modular construction
- o Does not require panel lettering.

3.2.2.3.4 Projection-Cue-Indicator Switches

The projection-cue-indicator switch will be applied more frequently to integrated crew station control panels. The ability to interface these indicator switches through encode/decode logic via the computer for display of functional formats

Table 3-12. Switches

ITEM	SWITCH TYPE	INTERFACE		PRESENT USE (*RATING)	(1971-1974) FUTURE USE (*RATING)	RECOMMENDED SWITCH TYPES FOR PANEL USE
		DIGITAL	ANALOG			
NON-ILLUMINATED SWITCHES						
1.	ROCKER					
2.	SLIDE				1.0	X
3.	TOGGLE			3.3	0.5	X
4.	ROTARY			2.0	0.2	X
5.	PUSHBUTTON	X		2.5		
6.	LEVER					
7.	THUMBWHEEL	X		1.8	0.2	X
8.	INTERLOCK					X
9.	KEY	X			0.1	X
10.	KNIFE					X
11.	COAXIAL					X
12.	CIRCUIT BREAKER					X
ILLUMINATED INDICATOR SWITCHES						
1.	ROCKER	X				
2.	PUSHBUTTON	X		0.4	5.0	X
3.	THUMBWHEEL	X			0.1	X
PROJECTION-CUE-INDICATOR SWITCHES						
1.	12 MESSAGE DISPLAY	X			2.9	X

*RATING OF SWITCH USE: 0 - MINIMUM USE
10 - EXTENSIVE USE

makes this type of switch adaptable to the integrated electronic control panels.

Advantages of these switches include:

- o Multiple readout cues for a single switch
- o Color for cueing and verification
- o Low voltage logic for lamp drive
- o Flush mounted switches
- o Modular construction
- o Does not require panel lettering.

3.2.2.3.5 Message Indicators

Table 3-13 illustrates the various messages indicator types. These message indicators have single or multiple message outputs that can be logically selected. A multiple message indicator having a message catalog greater than ten is also referred to in the category of "Readouts" because this "Message Indicator" can be used as for numerical presentations.

3.2.2.3.6 Readouts

A readout refers to a numeric and/or alphanumeric panel display to the operator (see Table 3-14). The present readout device can formulate this numeric or alphanumeric by any one of the following methods:

- o Transparency projection
- o Printed character
- o Plasma
- o Lamp filament
- o Electroluminescent
- o Light Emitting Diodes (LED)
- o Tape or belt
- o CRTs.

Table 3-13. Message Indicators

ITEM	TYPE	VOLTAGE DRIVE		PRESENT USE (*RATING)	(1971-1974) FUTURE USE (*RATING)	RECOMMENDED FOR FUTURE PANELS
		≤6V	>100V			
1.	SINGLE MESSAGE: A. ELECTROMAGNETIC B. LAMP C. EL PANEL D. PLASMA	X X	X X	8.0	4.0	X X
2.	MULTIPLE MESSAGE: A. LAMP B. EL PANEL C. STEPPING MOTOR PROJECTION D. ELECTROMECHANICAL	X X X	X	2.0	4.0 1.0 1.0	X X X

* RATING: 0 - MINIMUM USE
10 - EXTENSIVE USE

Table 3-14. Readouts

ITEM	TYPE	VOLTAGE DRIVE		PRESENT USE (*RATING)	(1971-1974) FUTURE USE (*RATING)	RECOMMENDED FOR FUTURE PANELS
		≤6V	>100V			
1.	ELECTROMECHANICAL	X		9.0	2.0	X
2.	DIGITAL-RELAY	X				
3.	STEPPING MOTOR PROJECTION	X	X			
4.	LAMP-PROJECTION:					
	A. MOSAIC (NUMERIC)	X				
	B. DOT (NUMERIC)	X				
	C. SEGMENT (NUMERIC)	X				
5.	LAMP-FILAMENT:					
	A. PINLITE (NUMERIC)	X		1.0	1.0	X
	B. PINLITE (A/N)	X				X
6.	PLASMA:					
	A. SEGMENT		X			
	B. NUMERIC		X			
7.	ROTATING DRUM-STROBE		X			
8.	EL SEGMENT		X			
9.	LIGHT EMITTING DIODE:					
	A. DOT	X			2.0	X
	B. SEGMENT	X			4.0	X
10.	CRT	X		2.0	4.0	X

*RATING: 0 - MINIMUM USE
10 - EXTENSIVE USE

The future readouts for display panels will be limited because a common data display using a centralized device can present the numeric and alphanumeric status of all equipment in only one location. Panel mounted high voltage readouts will have limited use. The filament type readout and light-emitting diode readout which can be driven by ICs will have an advantage over plasma and electroluminescent devices. The tape or belt type readout device has a capability of up to 64 characters and special symbols. This capability is difficult to achieve with any of the other readouts, however, the device has definite mechanical drawbacks.

3.2.2.3.7 Meters

Meters presently in use for scaled measurements on panels include the analog current movement and mechanical tape meters. Development on both the segmented electroluminescent tape and LED tape meters has been underway for some time. The electroluminescent tape meters (see Table 3-15) appear closer to actual use than LED. The electroluminescent does require high voltage (300 volts RMS). The future of LEDs with their low voltage drive (1.2 volts dc) and compatibility with T²L makes replacement of electroluminescent very possible. The tape meters are also referred to as thermometer type meters.

3.2.2.3.8 Dials

Table 3-16 illustrates only a few of the many dial types available for front panel use. The use of accurate dials would be required only for measurements or reference setups. In most cases, panels would not require this accuracy, and direct readouts will replace dials.

Table 3-15. Meters

ITEM	TYPE	SIGNAL		PRESENT USE (*RATING)	(1971-1974) FUTURE USE (*RATING)	RECOMMENDED FOR FUTURE PANELS
		CURRENT	VOLTAGE			
1.	SEALED MOVEMENT	X		1.5	1	
2.	DUAL MOVEMENTS	X		1.5	1	X
3.	MECHANICAL TAPE	X		5		
4.	ELECTROLUMINESCENT TAPE		X	2	3	
5.	LIGHT-EMITTING DIODE TAPE AND DOT		X		5	X
6.	MECHANICAL COUNTER	X				X

*RATING: 0 - MINIMUM USE
10 - EXTENSIVE USE

Table 3-16. Dials

ITEM	TYPE	SIGNAL		PRESENT USE (*RATING)	(1971-1974) FUTURE USE (*RATING)	RECOMMENDED FOR FUTURE PANELS
		CURRENT	VOLTAGE			
1.	COARSE/VERNIER (1:1, 100:1)					
2.	MINIATURE DIGITAL (1 PART IN 1000)					
3.	DIGITAL DISPLAY (6 MIN. OF ARC)					
4.	POT. DIALS (3 TO 10 TURN)					X

*RATING: 0 - MINIMUM USE
10 - EXTENSIVE USE

3.2.2.3.9 Control Knobs

No table of knobs is given. They come in all forms, shapes, and colors. Knob types include:

- o Control
- o Pointer
- o Lock
- o Dual
- o Skirted
- o Tactile
- o Fluted
- o Bar.

3.2.2.3.10 Potentiometers

There are many types of potentiometers: cent-tap, variable function, etc. They are constructed using three different technologies: wirewound, carbon, and film. Most pots are directly interfaced with equipment for some form of threshold bias or gain control.

3.2.2.3.11 Resolvers

Resolvers are primarily magnetic or resistive. The magnetic resolvers are used for narrow-band application that require high reliability. Additional circuits such as synchronous detectors, feedback amplifiers, and electronic clamps tend to make magnetic resolver application expensive. The resistive resolver-potentiometer is either wirewound, carbon, or film. It can be used for wideband applications of infinite resolution. The wideband function is normally dc coupled through the potentiometer to the sine and cosine amplifiers. Contact wear is the disadvantage of the resolver-potentiometer.

3.2.2.3.12 Timing Indicators

Equipment often has elapsed time indicators as part of the control panel or equipment. Elapsed time indicators are necessary for preventive maintenance but have the following disadvantages:

- o Servo systems have increased errors due to gear wear as a function of the time the equipment is used.
- o Special electron devices age with use and are scheduled for replacement as a function of time.

Types of timing indicators include:

- o Countdown
- o Impulse
- o Stepper
- o Synchronous motor
- o Chemical color change.

3.2.2.3.13 CRT/Operator Hand Controls

The purpose of the hand control is to permit the operator to manipulate the sensor and computer inputs to the CRT and provide some "action" output. Some of the operational uses for "CRT/Operator Hand Controls" include:

- o Call-up of memory information
- o Interface means for diagnostic checkout
- o Track-update of experiment target
- o Determine coordinates of experiment
- o Designation of off-set for display.

Table 3-17. CRT/Operator Hand Controls

ITEM NO.	TYPE	OUTPUT		PRESENT USE (*RATING)	(1971-1974) FUTURE USE (*RATING)	RECOMMENDED FOR FUTURE PANELS
		ANALOG	DIGITAL			
1.	POSITION TYPES: A. GIMBALED B. UNIVERSAL JOINT C. BALL JOINT/CENTER RETURN D. STIFF-STICK E. TRACK BALL	X X X X	X X	4 2 1	5 2	X X
2.	RATE TYPES: A. STIFF-STICK B. PRESSURE	X X	X X			X
3.	SPECIAL: A. RESOLVER B. POTENTIOMETER C. AZ/RG STICK D. LIGHT PENCIL OR GUN E. VIDEO MATRIX AND KEYBOARD F. PUSHBUTTON MEMORY INDEX	X X X X	X X	1 2	1 2	X X X

*RATING: 0 - MINIMUM USE
10 - EXTENSIVE USE

"CRT/Operator Hand Controls" include the position controls, rate controls, light pens, and other special controls. A detailed list is provided by Table 3-17.

3.2.2.3.14 Keyboards

Present and future avionic equipment utilize the keyboard for data insertion. Avionics equipments tend toward dedicated keyboards for preselect-channel selection and/or for manual frequency insertion to the communications equipment. However, the future avionic systems will have a modified keyboard at each operator position interfaced via the General Purpose Digital Computer to all associated equipment. Present keyboard implementations include:

- o Solid-state light switch keys
- o Mechanical keys
- o Capacitive keys
- o Hall-Effect keys.

The Hall-Effect key switch will replace mechanical switching. However, the use of key movement will be retained because the general response of users indicates the desire for "feel or touch" when keying a message.

3.2.2.3.15 Recommended Component Selection - Present Modification Kit Design (1968-1970)

The equipment built in 1968-1970 will retain in the majority of cases dedicated electronic control panels. It will require time for the military services to put into effect standard equipment interfaces that will convey to equipment builders the interest of the military to integrate controls. Thus, the component use for equipment, especially modification kits, that will find field use in this period must conform to selection standards because of logistic support.

3.2.2.3.16 Present System Design (1971-1974)

The equipment design for systems to be developed for period 1971-1974 will include components available today or presently in a development phase. These future systems will have a General Purpose Digital Computer, and the majority of controls will interface the equipments via the computer. There will be almost total integrated area station control panels. Most equipment in this time period will have standard digital interfaces. The component use for integrated area station control panels will have a marked change during this time period. The majority of control and display components will include:

- o Illuminated indicator pushbuttons
- o Projection cue indicator switches
- o Single message indicators (incandescent lamp)
- o Multiple message indicators (incandescent lamp and EL)
- o Readouts (lamp filament, electroluminescent and light emitting diodes)
- o Stiff-Stick and Track Ball controls
- o CRT tabular displays or deformographic storage
- o Keyboards (mechanical, capacitive, Hall-Effect).

These types of components lend themselves to computer interfaces for operator cueing, verification of switch selected, low voltage logic, limited panel space, standard wiring, flush mount, etc.

3.2.2.3.17 Future System Design (1974-1980) - General

The future system design (1974-1980) will consider total ICSCPs. The equipment will have, in most cases, a total digital interface even for volume, squelch, gains, etc. The controls will interface all equipment via the computer.

Monolithic devices or perhaps a replacement for transistor technology will bring about total digital interface equipment. There will also be, in this time period, a new generation of panel components for operator action inputs as well as visual cueing and display.

3.2.2.3.18 Future Operator Action Inputs

The "operator action" inputs to the system will be directed toward selecting modes and functions displayed to the operator by cue-indicators and pointing to particular location on a dynamic visual display. These action inputs are encoded for transfer to the computer. The "action device" itself is the concern of this paragraph and not the cue indicators which will be covered later.

3.2.2.3.19 Mode and Function Action Devices

The present switching devices used for mode and function selection include the toggle, rotary, microswitch, and sliding brush. All of the action inputs have some form of mechanical contact. The problems of contact wear, contact bounce, contact impedance, size and cost are present in this type of switch.

The future switches used for future interface action inputs will have no mechanical contacts. This approach will follow present keyboard developments using capacitive and Hall-Effect action keys which provide direct encoding with no contact wear or bounce. The added fabrication of capacitive or Hall generators as part of the logic package provides a low cost type of fabrication because the switch is only a moving plunger.

It is recommended that all switches for "action inputs" to the computer utilize capacitive and/or Hall-Effect methods of implementation.

3.2.2.3.20 Future Operator Cue-Indicators - General

The present cueing indicators include those listed in Tables 3-12 and 3-13 for Illuminated Indicator Switches, Projection Cue-Indicator Switches, and Message Indicators. Each of these cue indicators provides a visual format to the operator. More than one format can be called-up by the operator through a multiple cue transparency. Single format cueing can be implemented through engraving, printing or a transparency on a lens screen. The visual display of the format is by some source of illumination. The present applications use almost exclusively the incandescent lamp. The life of lamps is from 10 to 30 thousand hours; low voltage drivers for the lamps can be developed using available transistors.

The present development trends for cueing indicators of a single format use the following as light source:

- o Incandescent lamps
- o Electroluminescent panels
- o Plasma
- o Radiation materials
- o Light-Emitting Diode (LED).

Of all these light sources, the incandescent lamp enjoys the privilege of greatest demand. The reasons include good luminance, availability, cost, easy packaging, relatively good life, and low voltage operation. The electroluminescent and plasma sources require high voltage drivers, and future applications will limit their use. The LED could become a successor to the incandescent lamp because of its high brightness, low voltage, efficiency, and monolithic fabrication.

The use of electroluminescent and plasma lighting will depend on the cue panel implementation. If the cue panels are in a matrix, they could be illuminated by a single electroluminescent or plasma source. Thus, the application of a type lighting depends on whether multiple formats are being illuminated. It appears that the incandescent lamp will retain a majority of the applications because of its cost and wide spectral output. The projection type of format indicators will exclusively utilize the incandescent lamp.

3.2.2.3.21 Future Trend in Readout Devices - General

The present readouts available and in development are tabulated in Table 3-12. The contenders for electronic readouts include:

- o Light-Emitting Diodes (LED)
- o Incandescent filament segments (Pinlite)
- o Electroluminescent (EL)
- o Plasma
- o Numeric CRT.

All of these readouts, with the exception of the last, have a star-burst character configuration of 14 or 16 segments to display all alphanumerics (A/N). Numeric readouts normally use seven segments. The form-factor for the A/N or numeric readouts is fixed; therefore, only the numeric CRT readout can display multiple digits from a single device in one field-of-view. To accomplish this feat, a horizontal scan and a change in the form-factor of the characters is required. Manufacturers of test equipment are the large users of "readout devices."

In the time period from 1969 to 1972, modification of Equipment Control Panels to accommodate electronic readouts will be provided. This may well be termed a step toward integrated electronic control panels. This phase would retain the dedicated electronic control panel and keep control panel design in the hands of the equipment manufacturer.

3.2.2.3.22 Future of Readouts

From 1971-1978 there will be phase-out of the A/N and numeric electronic readouts from avionic control panels. With the concept of an ISCP, there will be a General Purpose Digital Computer that has in memory all the data now displayed on individual readouts.

The question naturally arises concerning the display device. Will the device be a CRT (conventional phosphor or storage tube), a deformographic tube, or some type of solid state matrix display? CRTs and deformographic tubes require some precautions in Space Station utilization because of fragility; however, this should not prohibit their use. Both tube devices and light-emitting diodes will find uses in the 1975 Space Station.

Holographic displays or the Kinoform* will come into being in the 1980 time frame if this development is accented. Development to date has primarily addressed the construction of holograms and long-term storage of holographic data. The real-time application of holograms and lasers for image construction requires extensive development activity. Applications for nonreal-time holography includes 360 degree image reconstruction and panoramic view with three-dimensional definition.

*IBM's name for a single diffraction order hologram.

3.3 MISSION ANALYSIS

Two key manned missions were analyzed with the objective of considering all significant aspects for flights over the next two decades. The first mission studied was the Earth Orbiting Space Station anticipated for the 1975-1985 time frame. The second mission was an Interplanetary Mars Flyby Mission which is expected to be flown after 1985. Primary emphasis was given to the Space Station because it will serve as a manned test base from which the next class of missions will evolve.

The launch of the Orbital Workshop, presently scheduled for the 1971-1972 time period, ushers in a new era of experiment opportunities in space. For the first time, manned Earth orbital missions will be conducted with major emphasis on scientific/technical activity rather than space vehicle technology. Precursor tasks and activities in the early workshop will clear the way for a full exploitation of space science and Earth applications.

With the unfolding of new vistas, there also accrues significantly new responsibilities in mission planning to establish connective and evolving activities for a mission which extends for years rather than weeks as previous missions have. Each task or activity, as well as each piece of equipment, must be properly coordinated with long duration mission requirements.

The mission analysis will draw from previous study efforts, by NASA^{1,2}, and industry^{3, 4, 5}, to select a representative time-phased experiment program for the 1975-1985 decade in space. The primary premise guiding the present effort is that precursor space missions, both manned and unmanned, will have provided an operations data base upon which future operations and applications can be

built. Notable among those already flown are OSO and OAO which provide survey maps of the sun and the stellar sphere respectively. In addition, these flights also provide much needed design parameters for future astronomical instruments.

Missions scheduled but not yet flown are expected to provide data on both crew capabilities and the operation of precision, high resolution telescopes in space, e.g., the five flights of the Orbital Workshop. Experiments included in the Orbital Workshop and the ATM are described briefly in Table 3-18. These experiments will help develop the methodology, procedures, criteria, data and equipment which will serve as a basis for the design of second generation space experiments for the Space Laboratory. Typical of the information needs which hopefully will be answered by early missions are:

- o Identification of potential targets for high resolution study
- o Space operations evaluation for man/machine interface design
- o Man's reaction to long-term zero "g"
- o Evaluation of equipment design and operation
- o Demonstration of the ability and need for succeeding generation experiments.

The manned interplanetary mission under most recent consideration is the 1986 Manned Mars Mission depicted in Figure 3-17. The mission profile is characterized by an out-bound, swing-by of the planet Venus on the 164th day of the mission, a Mars arrival at 367 days, a Mars departure at 427 days, and an Earth return on the 667th day. A multistage, multimodule configuration concept is based upon discussion held in August 1969 with members of NASA/OART Mission Analysis Division. Although the actual space vehicle may differ markedly from this configuration, the majority of the elements depicted will most probably appear in this mission as flown (Figure 3-18). The manned planetary configuration given detailed

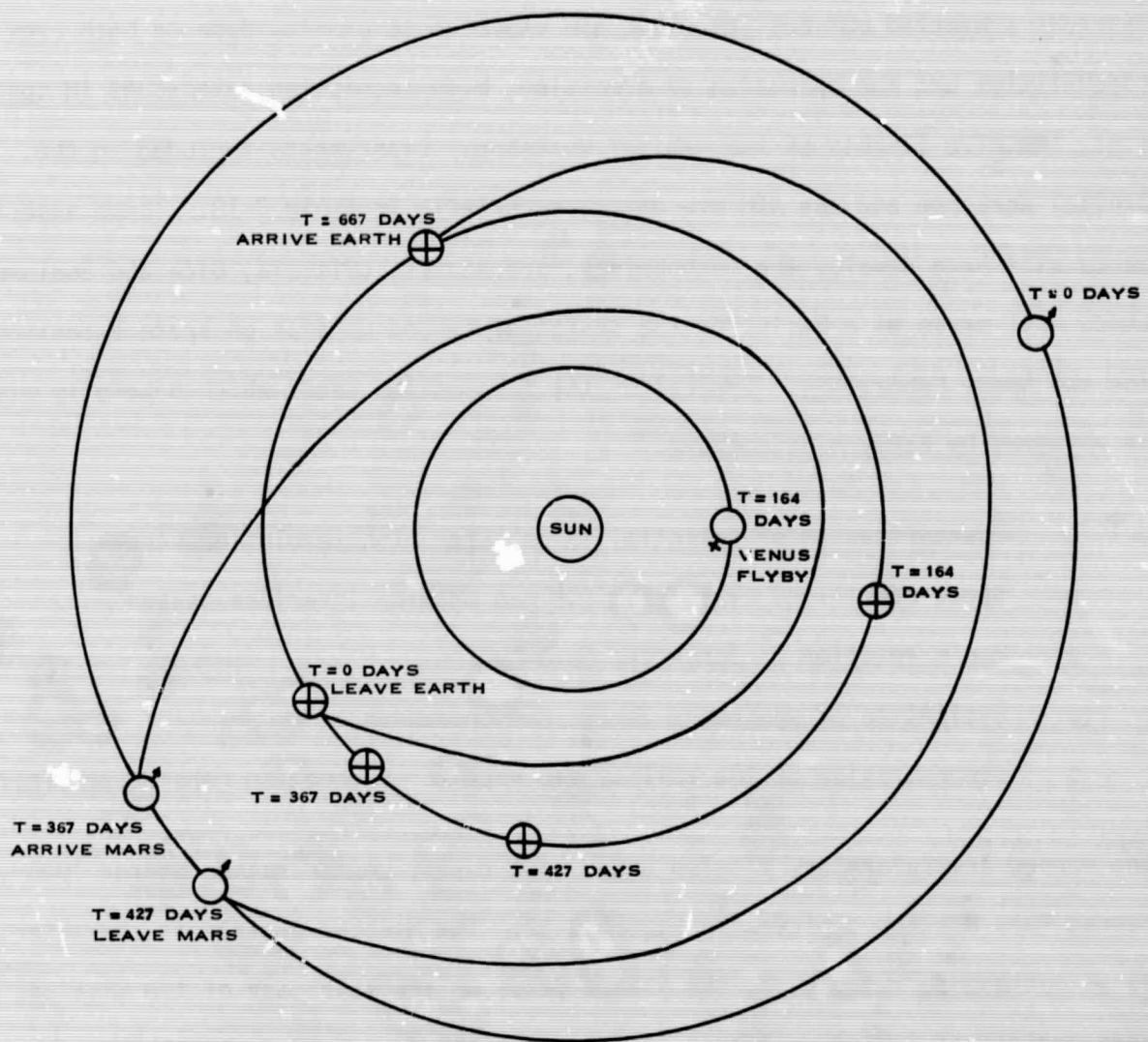


Figure 3-17. Mars Mission Profile

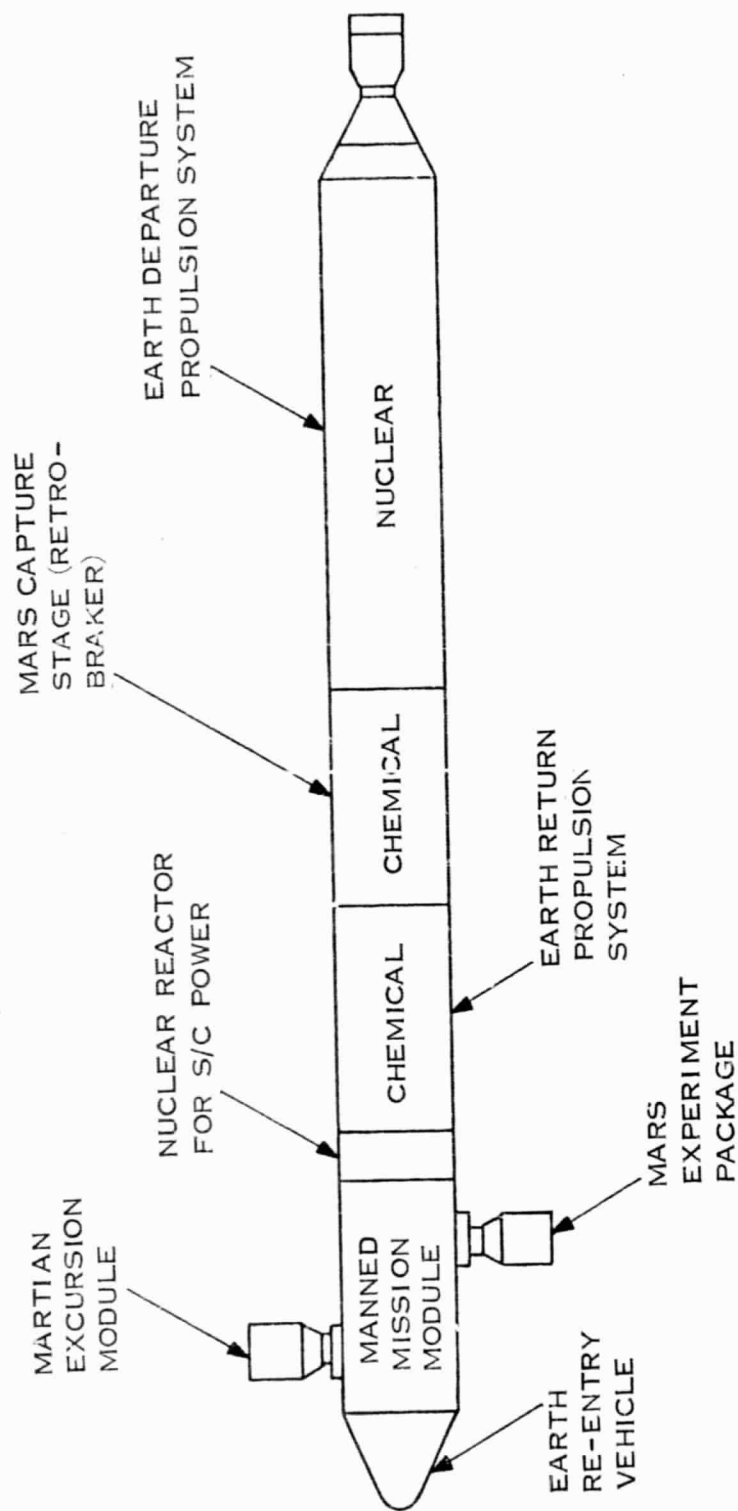


Figure 3-18. Manned Mars Mission Configuration

Table 3-18. Experiments Selected for the Orbital Workshop

<u>MSFC Number</u>	<u>Experiment Name</u>
D008.....	Radiation in Spacecraft
D019.....	Suit Donning and Sleep Station Evaluation
D020.....	Alternate Restraints Evaluation
D021.....	Expandable Airlock Technology
D022.....	Expandable Structure for Recovery
M018.....	Inflight Vector Cardiogram
M050.....	Metabolic Activities
M051.....	Cardiovascular Function
M052.....	Bone and Muscle Changes
M053.....	Human Vestibular Function
M055.....	Time and Motion Study
M056.....	Non-Gravimetric Mass Measurement
M058.....	Human Mass Measurement Device
M402.....	Orbital Workshop
M415.....	Thermal Control Coatings
M479.....	Zero G Flammability
M487.....	Habitability Crew Quarters
M508.....	EVA Hardware Evaluation
M509.....	Astronaut Maneuvering Equipment
S015.....	Effects of Zero Gravity on a Single Human Cell
S018.....	Micrometeorite Collection
S019.....	UV Stellar Astronomy
S027.....	Galactic X-Ray Mapping
S049.....	TR Interferometer/Spectrometer
S061.....	Potato Respiration
S071.....	Circadian Rhythm of the Pocket Mice
S072.....	Circadian Rhythm of the Vinegar Gnat
S075.....	Microwave Radiometer
S100.....	Metric Camera
S101.....	Multispectral Camera
S102.....	Dual Channel Scanner
S103.....	Short Wavelength Spectrometer
T003.....	Inflight Nephelometer
T017.....	Meteoroid Impact and Erosion
T018.....	Precision Optical Tracking
T020.....	Jet Shoes
T021.....	Meteoroid Velocity
T025.....	Coronagraph Contamination Measurement
T027.....	ATM Contamination Measurement
ATM-A.....	White Light Coronagraph
ATM-A.....	Ultraviolet Spectroheliograph and Extreme UV Spectrograph
ATM-A.....	Ultraviolet Spectrometer and UV Spectroheliometer
ATM-A.....	X-Ray Telescope
ATM-A.....	Imaging X-Ray Spectrographic Telescope

ORBIT 50° INCLINATION, 270 NM ALTITUDE

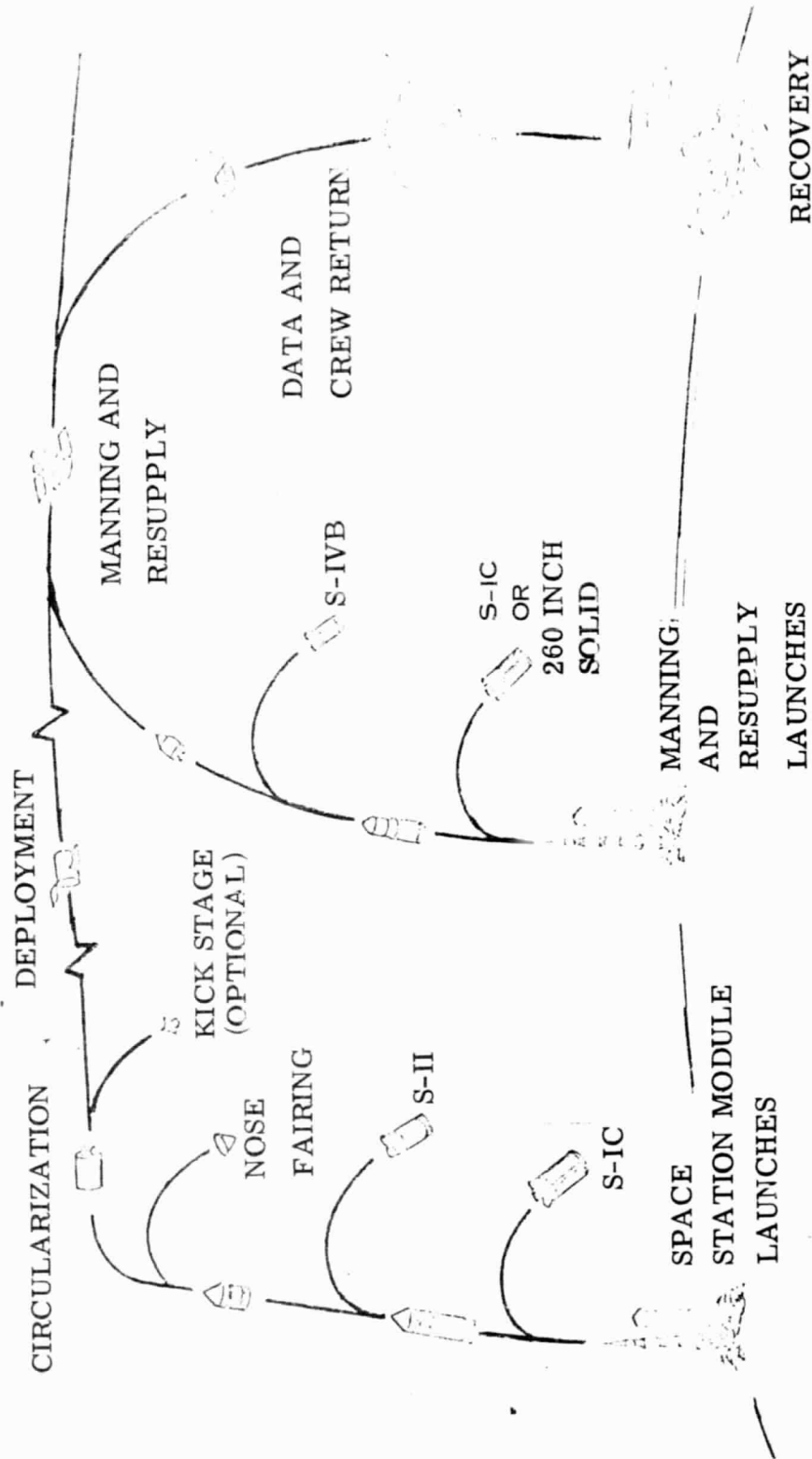


Figure 3-19. Mission Profile for Space Station Mission

treatment in the study is that defined in "Integrated Manned Interplanetary Spacecraft Concept Definition," Final Report Volumes I-IV, NAS1-6774, The Boeing Company, Seattle, Washington. Although this configuration is based on Apollo/Saturn hardware, the essential mission characteristics including multiple launches, orbital assembly, checkout and launch are present and pertain directly to the more recently considered nuclear powered mission.

3.3.1 Space Station/Base Mission

The Space Station/Base Mission is planned for the 1975 time period. Duration will nominally be two years with a goal of ten years lifetime. The specific configuration has not been selected, however, current concepts include incremental growth beginning with a 9 to 12 man capability which will increase toward a 60 to 100 man station in 1985. Still unsettled is the design issue of zero "g" versus artificial gravity, and resolving data is not expected before 1972-1973; therefore, development efforts include both versions. This section will discuss the Space Station mission, typical space vehicle configurations and the proposed experiment programs.

3.3.1.1 Mission Description

The evolution of Space Station/Base from the Orbital Workshop is shown in Figure 3-21. The right hand upper configuration is composed of modules, each with full survival capability including solar panels for power. Later launched modules, some of which are operated independently of the Space Station, will be dedicated to experiment activity. This configuration is typical of the zero "g" configuration. The right hand lower version shows one concept for providing artificial gravity for the crew. The central hub is nonrotating to accommodate the experiments which require zero "g" and will likely contain systems and

- STATION: 9 - MAN NOMINAL, MLV-21 LAUNCH VEHICLE

- MANNING: S/C 9 - MAN BIG GEMINI/SOLID/S-IVB

- MANNED LAUNCH (↑), UNMANNED LAUNCH (↗) EXPERIMENT MODULE (Δ)



Figure 3-20. Major Mission Events

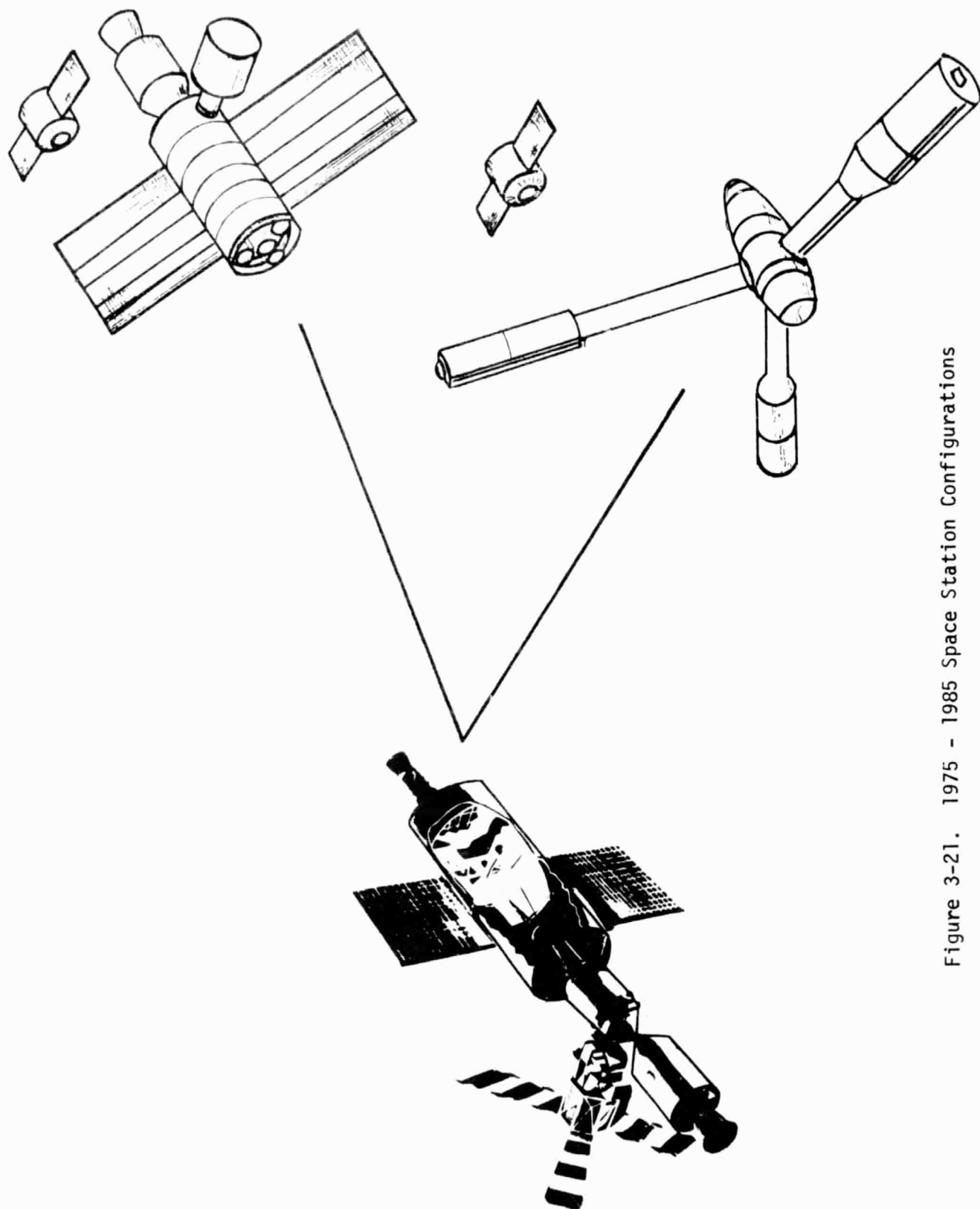


Figure 3-21. 1975 - 1985 Space Station Configurations

experiments with difficult point requirements. Power to the rotating station will be provided by nuclear power systems remotely located on one of the rotating arms.

3.3.1.3 Experiment Program

Experimentation for the Space Base will take scientists and astronauts far afield from present roles and methods pursuing new technologies and responses to unexpected findings. Apart from information needed to extend the usefulness of man and machines, e.g., technological, behavioral, and medical experiments, the press is still on to provide both abstract and practical knowledge in the science and applications areas. In addition, early efforts in space will be directed toward identifying a product potential using the unique environments of space. Experiment activities in each area are:

- o Future space flights
 - Biomedical/Behavioral
 - Future space flight development (procedures, methodology, and equipment)
 - Space biology
- o Applications
 - Space manufacture
 - Earth sciences
- o Space sciences
 - Astronomy
 - Space physics.

What will be done in each of these areas will of necessity depend on precursor results; therefore, the program will tend to be adaptive and hold to no rigid schedule. Planning for such a mission will include a real-time response capability.

Within the context of the program forcing function listed, a framework of program requirements may be established wherein experiment goals can be established and met. It is necessary that the framework be definite enough that milestones can be recognized and systems development problems do not get out of hand. Table 3-19 indicates three phases for an evolutionary experiment program. Although the experiment programs for each time period seem to consist of similar groupings, such is not the case. Experiment program accomplishments achieved in each mission phase will provide reevaluation data for improvement, augmentation or even redesign for subsequent program phases. In general, each time phase will evolve into the next with each successive accomplishment used to optimize the total results.

Representative experiment activities in each of the emphasis areas were selected and analyzed both as to sensor application for direct support requirements and sensor/system characteristics for indirect support system analysis. Tables 3-20, 21, and 22 detail the activities chosen for the mission. As discussed previously, these groupings provide only a systems analysis and program planning tool rather than a concrete system/sensor mix for specific mission periods. These groupings are responsive to established objectives in their respective time phases but can be expected to change in response to mission scheduling.

Operations analysis of the selected activities provides a validity check for planning. Usually, the configuration operation mode and crew size will have been

Table 3-19. Experiment Program Emphasis - Time Phased

1975	1979	1983
Astronomy	Astronomy	Astronomy
Biomedical	Biomedical	Biomedical
Earth Resources	Advanced Earth Resources	Earth Resources Laboratory
Engineering/Operations	Engineering/Operations	Engineering/Operations
Advanced Technology	Advanced Technology	Advanced Technology
	Space Biology	Space Biology
	Space Physics	Space Physics
	Space Manufacturing	Space Manufacturing

Table 3-20. Space Station Experiment Groupings - Core
(1975 Typ)

Biomedical (IMBLMS)

- Alveolar-Arterial Oxygen
- Regional Blood Flow
- Venous Pressure
- Cardiac Output
- Hematological Measurements
- Breath-by-Breath Measurements
- Metabolism
- Bone Densitometry
- Ancillary Experiments

Engineering/Operations

- EVA Mobility
- Maintenance Evaluation

Advanced Technology

- Miscellaneous Tests (Materials)

Earth Resources

- Metric Camera
- Multiband Photography
- Dual Channel Scanner/Imager
- Short Wavelength IR Spectrometer
- IR Interferometer/Spectrometer
- Microwave Radiometer

Astronomy

- UV Photographic Survey
- Far UV Spectograph
- Stellar UV Spectrometry
- Large Area X-Ray Detector
- Lo-Energy γ -Ray
- γ -Ray Spectroscopy

Table 3-21. Space Station Experiment Grouping - Medium
(1979 Typ)

Biomedical (IMBLMS)

See Core Grouping

Earth Resources

- Updated Core System
- Absorption Spectrometer and Imager
- UV Luminescence Spectrometer and Imager
- Laser Altimeter
- Long Wavelength Spectrometer
- Advanced IR Sounder
- Advanced Microwave Sounder
- Advanced TV System
- Advanced Radio Occultation
- Subsatellite Experiments

Engineering/Operations

- EVA Tests
- Maintenance Evaluations
- Space Station System Evaluation
- Experiment Module Evaluation

Advanced Technology

- Materials Tests
- Deployment Structures
- Fluid Systems

Space Biology

- Bio-C Microbiology
- Bio-D Small Vertebrates
- Bio-E Plants
- Bio-F Invertebrates

Astronomy

- High Energy Stellar B
- ATM Solar
- ATM Advanced High Energy

Space Manufacturing

- Process Manufacturing Tests
- Molecular Cohesion Tests

Space Physics

- Ionospheric Plasma Investigations
- Airlock Investigations

Table 3-22. Space Station Experiment Groupings - Balanced
(1982 - 1985 Typ)

Biomedical (IMBLMS)

Core Grouping
Evolving into
Small Hospital

Advanced Technology

- Life Support Systems Studies
- Power Systems Studies

Earth Resources

- Advanced Earth Resources and Meteorology Lab

Space Biology

- Biotechnology Lab

Engineering/Operations

- EVA Tests
- Free Flying Module Evaluations
- Space Station System Evaluations
- Experiment Module Evaluations
- Maintenance Evaluations

Astronomy

- ATM Advanced Solar
- ASTRA
- NASO

Space Manufacturing

- Pilot Manufacturing System

Space Physics

- Space Physics Lab

Experiment Discipline	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Biomedical	2.0	2.0	2.0	3.0	4.0	2.0	2.0	2.0	4.0	4.0	4.0
Engineering Operations	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	6.0	8.0	10.0
Astronomy	1.2	1.8	2.2	6.6	7.6	5.0	8.0	8.6	8.0	10.0	12.0
Small											
Medium											
Large											
Earth Resources	1.0	1.4	1.4	2.0	2.0		6.0	6.0	8.0	6.0	4.0
Small Earth Resources & Meteorology											
Intermediate Earth Resources & Meteorology											
Advanced Earth Resources & Meteorology											
Advanced Meteorology											
Space Biology											
Small-Bio C, D, E, F		.4	.2	.4	.8	1.6	2.0	4.0	4.0	6.0	6.0
Large											
Communications	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2
Advanced Technology	.2				1.0						
Small											
Medium											
Advanced											
Space Manufacturing						4.0	4.0	6.0			8.0
Average Crew Size	6.6	7.8	8.0	14.2	17.6	14.8	25.2	30.8	32.2	36.2	45.2

NOTE: These are Average Experiment Crew Requirements.

Figure 3-22. Space Station Experiment Operation Schedule

established or at least bounded prior to analysis; however, as a design or planning tool, operations analysis can be performed open ended against a list of activities to determine feasibility or reasonableness with respect to operations support requirements. Results of analyses using the latter approach are presented in following figures. The first (Figure 3-22) is a summary across the total mission program for each of the emphasis areas showing the number of support personnel required exclusive of mission requirements. Note that the crew requirements, varying from approximately seven men in 1975 and increasing to 45 men by 1985 represents the crew complement for experiments only.

Experiment activities were defined in more detail for a typical day (EVA day) during the early mission phase (Figure 3-23). Not all emphasis area activities appear on the chart; some were not scheduled for this particular day. Using the figure, a timeline of crew requirements and data volume generated was determined and are shown in Figure 3-24.

3.3.1.4 Experiment Operations

Day-by-day scheduling will be a function of mission control and crew availability, factors which are beyond the scope of this study. In lieu of scheduling, each experiment activity was presumed to be operated at a rate which accomplished its objectives within one year. The data rates and data form given are those anticipated for equipment in the scheduled time frame.

Early mission phase experiments which generate image data will, by virtue of resolution requirements, use photographic film as the recording media. Experiment monitoring for control and ground visibility is accomplished by a closed circuit video system which includes a recording capability that can select sample frames

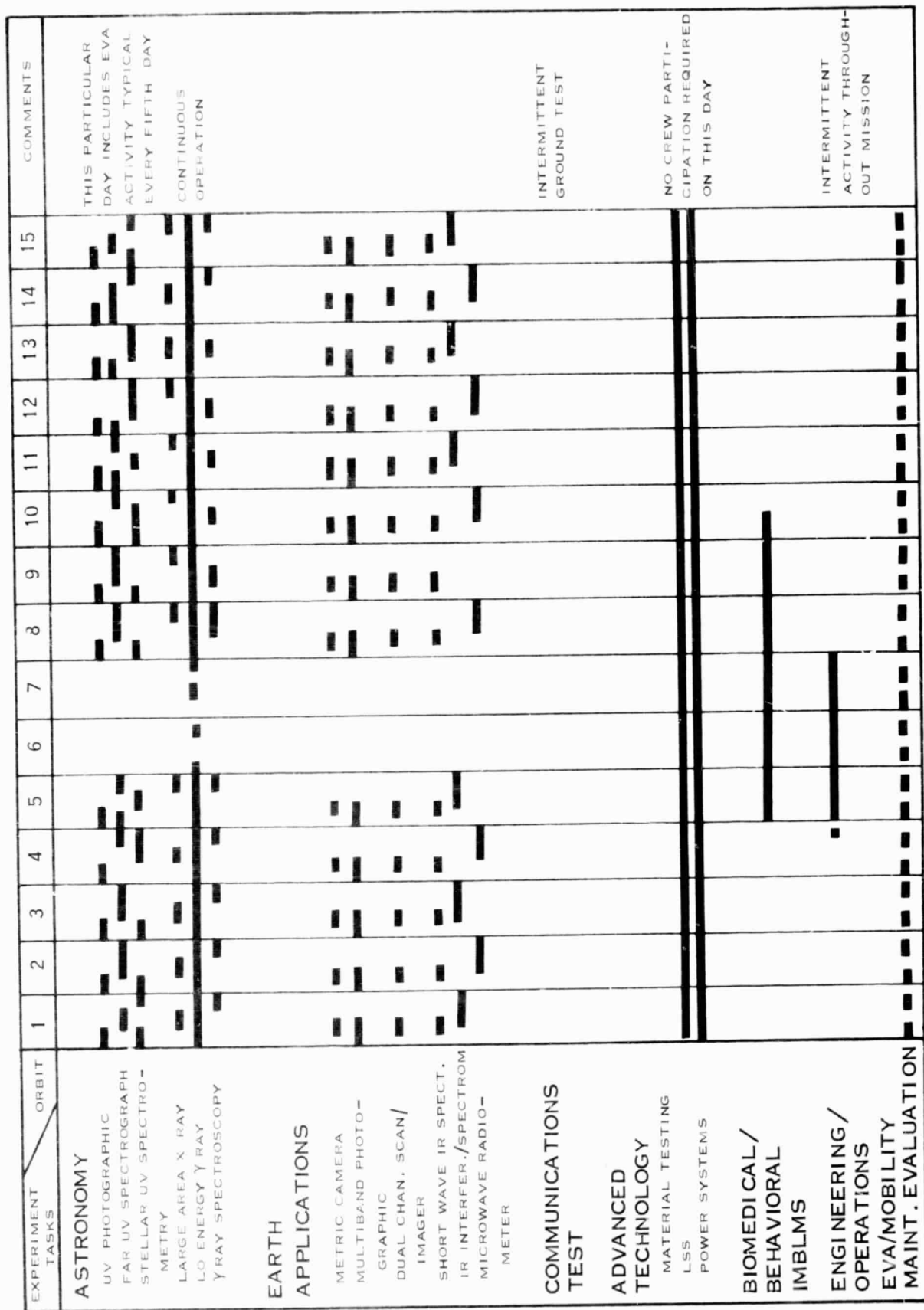


Figure 3-23. Experiment Timeline - Core (Typical)

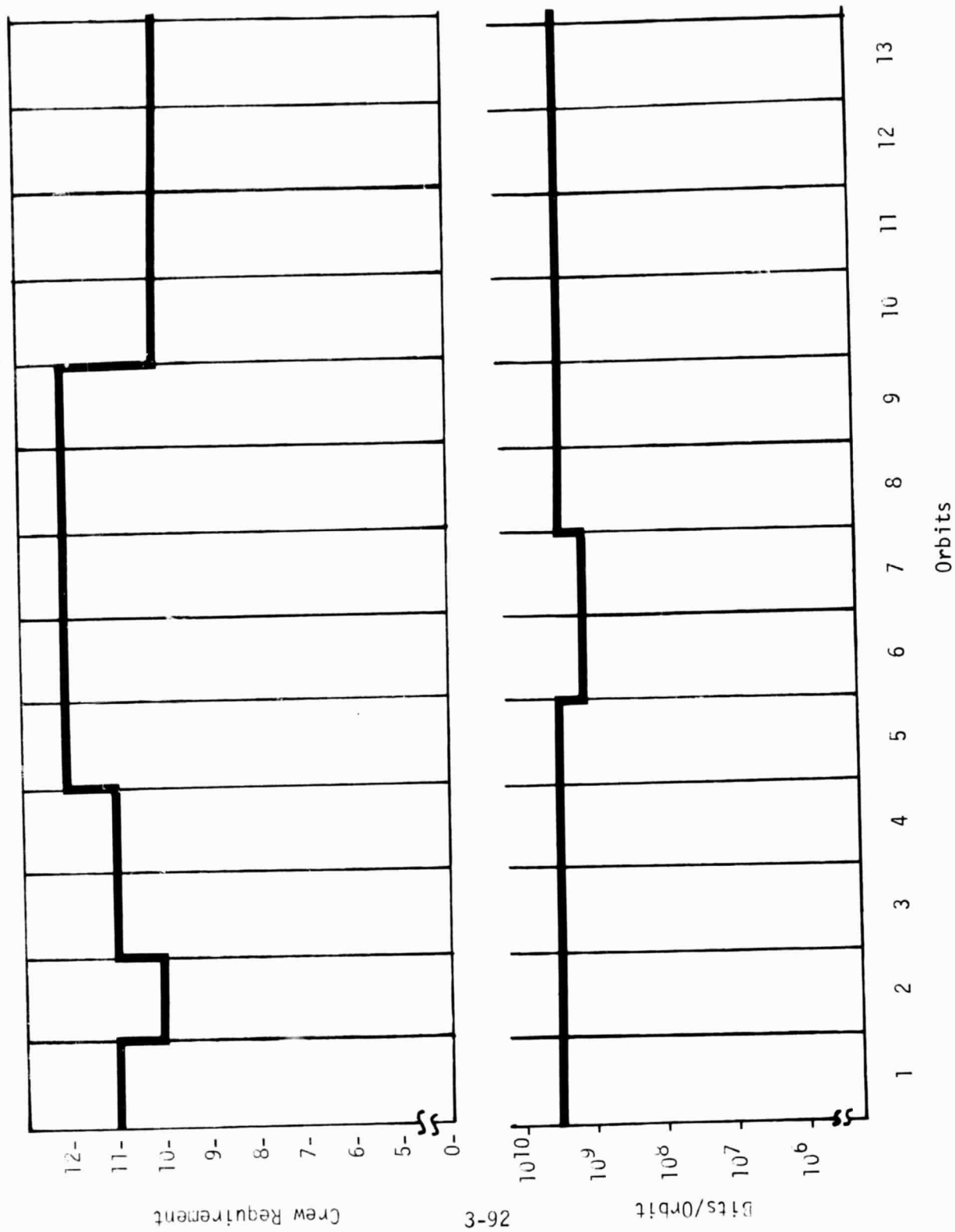


Figure 3-24. Crew and Data Timeline

for transmission to the ground at a rate compatible with both visibility requirements and down link bandwidth. Initial processing of film, desirable from a radiation damage point of view, is difficult due to the lack of simple processing techniques for color film.

The data processing system(s) will provide experiment control and correlate experiment data with housekeeping measurements. Each experiment will require secondary support depending on operational mode for stabilization, position location, time correlation, docking systems, etc.

Previous experience with experiment integration has resulted in the identification of support requirements and analysis methodology for individual experiments.

Supporting requirements include:

- o Structural/mechanical
- o Electrical
- o Display and control
- o Stabilization and control
- o Communications/data handling
- o Man/machine interface.

To date, these support capabilities have been custom designed without considering system growth or flexibility.

The Space Laboratory experiment support systems include all of the elements mentioned plus other aspects which did not apply previously. Crew and mission time availability will allow large segments of the experiment program to be completed and replaced several times during the mission. Each of the support elements must be designed to accommodate this evolution. Other significant

features of continuing orbital support systems are:

- o Checkout/maintainability
- o Data analysis for experiment control
- o Experiment replacement/logistics
- o Skill specialties
- o Space Station autonomy
- o Real-time activity scheduling.

3.3.2 Manned Interplanetary Flyby Mission

The Mars Flyby Mission selected for study includes a hyperbolic encounter with Mars and a free return to Earth.⁶ The spacecraft mission module carries the following:

- o Crew of four
- o Payload for inflight experiments and observations
- o Mars orbiting and landing probes
- o Mars surface sample return probe.

The Earth reentry module will be either a modified Apollo command module or a new vehicle design, e.g., the biconic design which can enter the Earth's atmosphere at velocities up to 65,000 fps.⁷ The reentry module for the Flyby Mission must carry a crew of four and will attain 50,000 fps for a direct aerodynamic reentry.

The Earth launch vehicle is a two-stage Saturn V vehicle consisting of an Up-rated S-IC first stage and an S-II second stage. Three modified S-IVB (S-IVC) stages will be used for transplanetary injection. The selection of the S-IVC stages for mission implementation was made for study convenience only. Once developed, it is more likely that nuclear stages will be used, rather than chemical, for all post-Earth launch staging.⁸ The orbital assembly operations for the Flyby Mission

will require more launches than can be accommodated by the presently funded facilities.⁹ Reuse of launch facility elements is, therefore, required. As a result of the significant intervals between module launches (perhaps 6 - 12 months separating first and last), the problems associated with orbital storage and preplanetary launch checkout merit consideration.

3.3.2.1 Mission Description

The mission profile⁸ for a typical flyby mission is shown in Figure 3-25. Mission parameter data shown in Table 3-23 indicates a mission lifetime of 667 days and communication distance at encounter to be 0.75 AU. The spacecraft distance variations are plotted in Figure 3-26, and it should be noted that while the maximum distance from the spacecraft to the sun is only 2.2 AU, the maximum spacecraft to Earth communication distance is 3.2 AU at aphelion.

The S-IVC engine firing sequence is shown in Figure 3-27 for the spacecraft launch from Earth orbit. After separate Earth launches, rendezvous and docking in a 263.5 nautical mile circular orbit, the orbital launch vehicle and spacecraft enter a highly elliptical intermediate orbit using a complete burn of the first S-IVC and a partial burn of the second. After one complete revolution in this orbit, a restart and burn of the second S-IVC and full burn of the third S-IVC at perigee will provide the necessary planetary injection velocity.

3.3.2.2 Earth Orbit Assembly Operations

The orbital launch vehicle will consist of the spacecraft (including reentry vehicle) and three S-IVCs in tandem. The Earth launch and vehicle assembly sequences are shown in Figure 3-27. Four Saturn V launches are required to

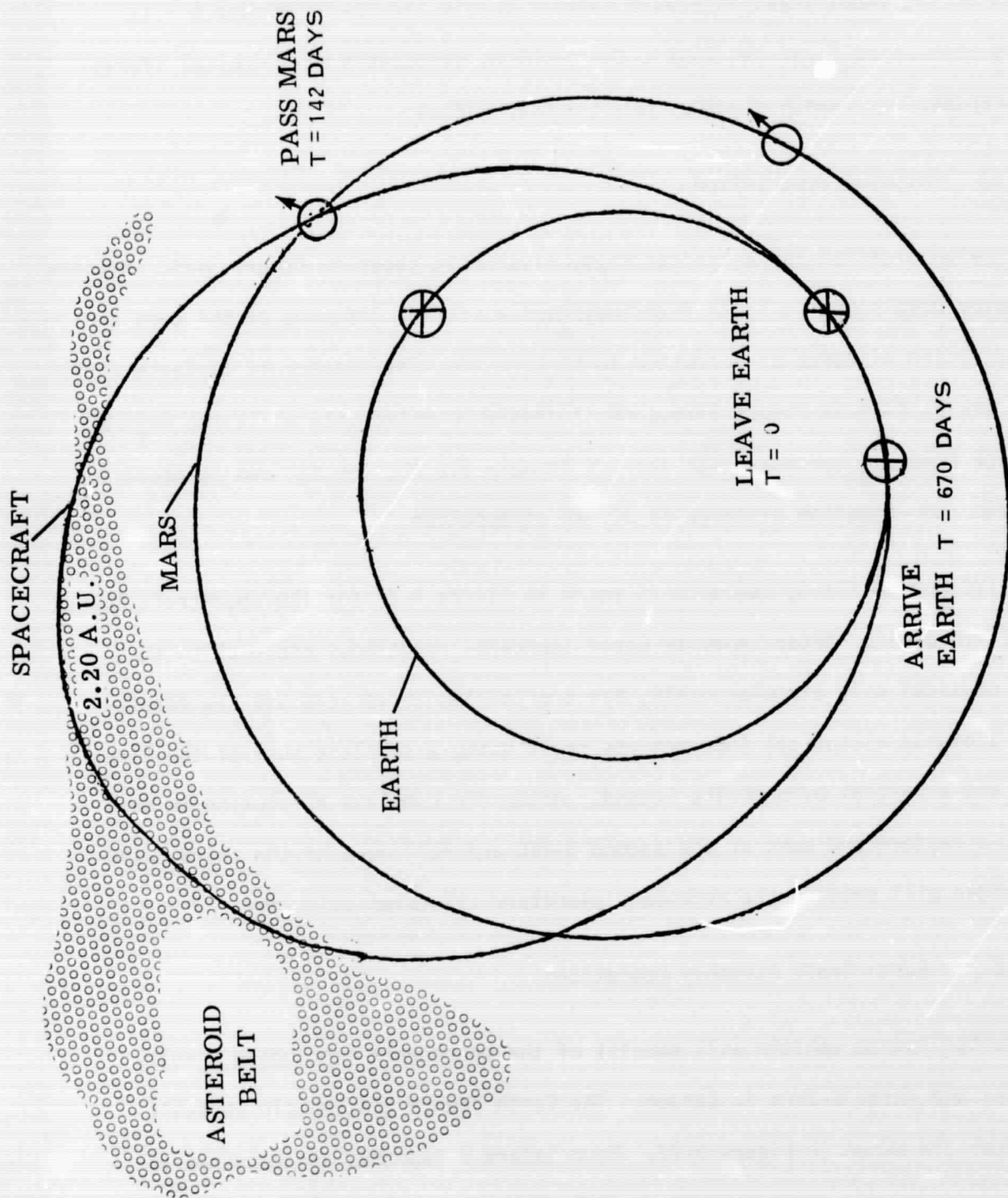


Figure 3-25. Flyby Mission Profile

Table 3-23. Mars Flyby Typical Mission Parameters

Mission Parameter	Value
Earth Departure V, fps	15,400
Earth Return V, fps	49,100
Mission Duration, Earth Days	667
Outbound Time, Earth Days	130
Mars Encounter Velocity, fps	31,600
Encounter Period, Minutes	127
Mars Encounter Altitude, NM	460
Communications Distance at Encounter, AU	0.75
Aphelion Distance, AU	2.213
Earth Departure Asymp. Declination, Degrees	33
Notes: (1) No propulsion after transplanetary injection (2) Earth departure circular orbit altitude - 262 NM (3) Encounter period is equal to time spent within ten planetary radii of Mars by spacecraft	

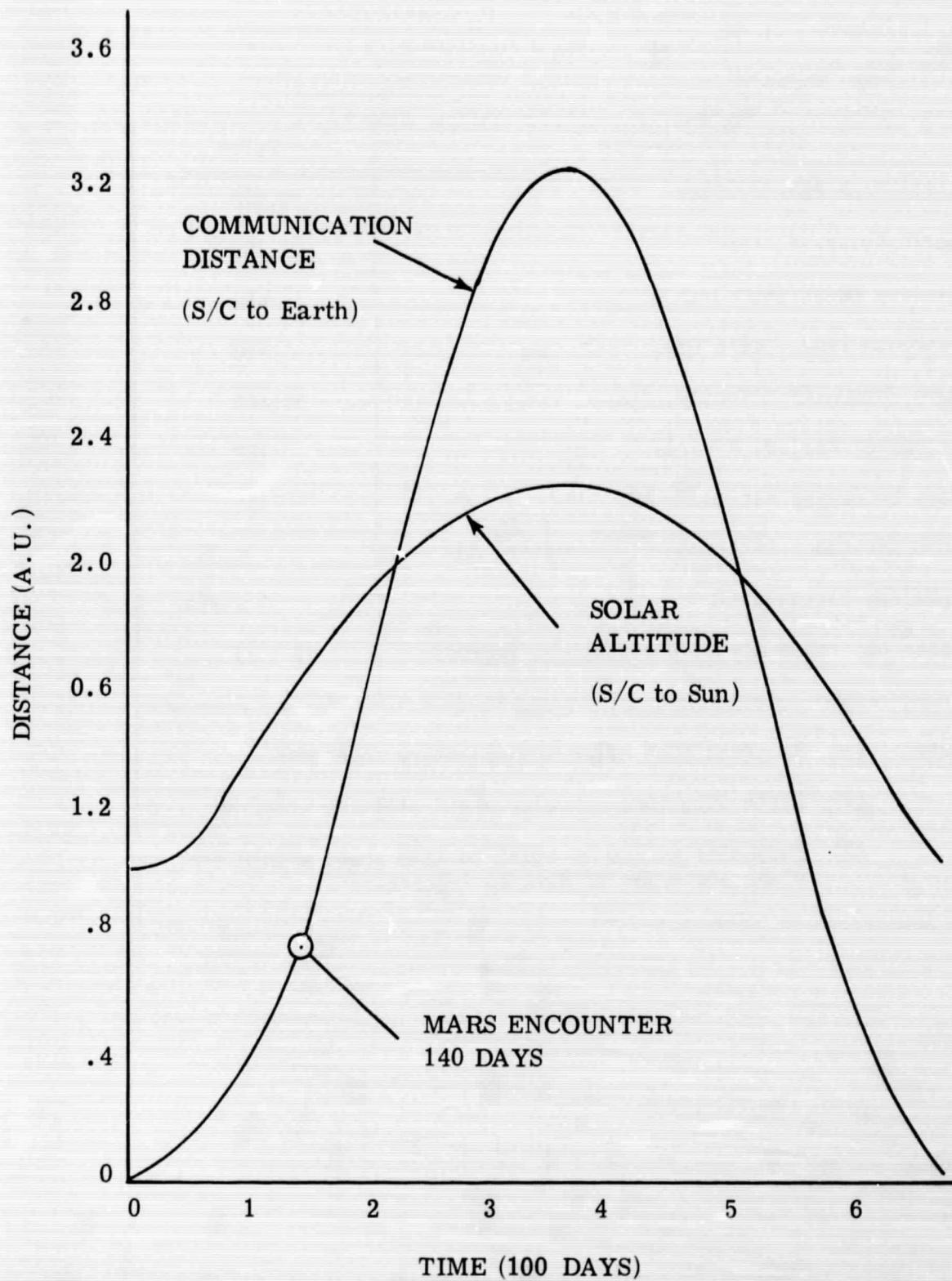
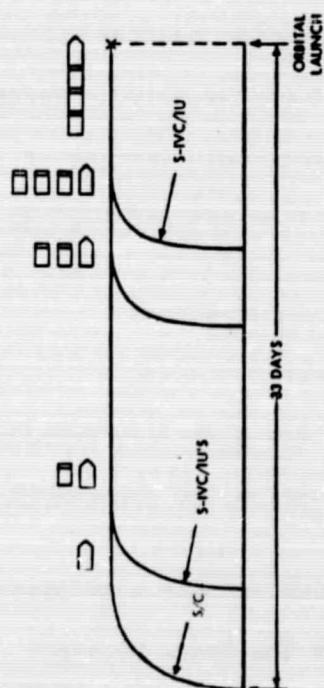
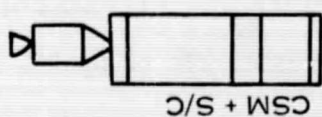
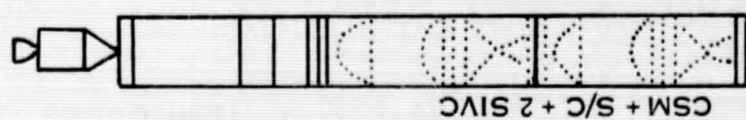
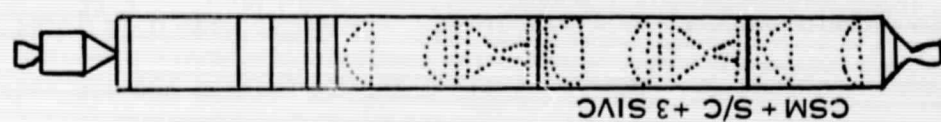


Figure 3-26. Earth-Mars-Earth Interplanetary Trajectory



VEHICLE ASSEMBLY SEQUENCE

EARTH LAUNCH SEQUENCE

Figure 3-27. Earth Launch and Vehicle Assembly Sequence for Mars Flyby Mission

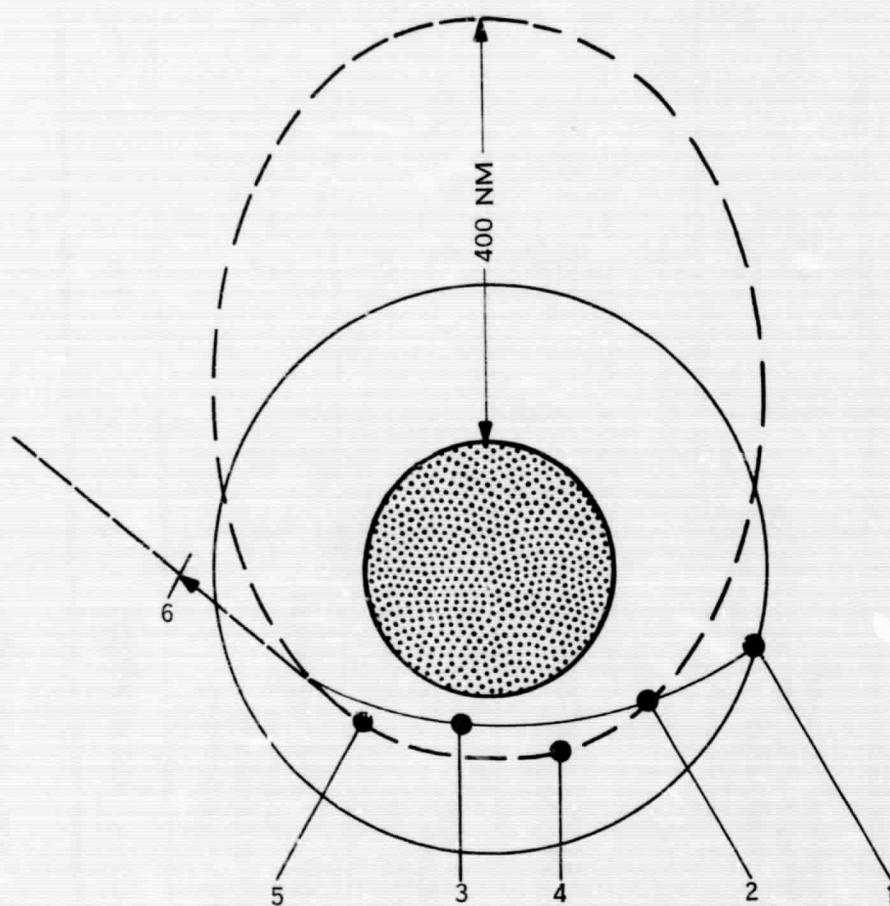
place the flyby mission modules in Earth orbit. The first launch is injected into a 100 x 262 nm elliptical transfer orbit. The S-II stage and the inter-stage structure is jettisoned during the Earth orbit coast period. The CSM is then separated from the spacecraft, and after the CSM adapter is jettisoned, the CSM turns around and redocks with the spacecraft. The orbit of the spacecraft/CSM is then circularized at 262 nm by the SM propulsion unit.

Launches 2, 3, and 4 place the three S-IVCs into a 100 nm circular orbit. After the nose cone and interstage structure have been jettisoned, an idle mode burn of the J-2S engines transfers the S-IVCs into the spacecraft's 262 nm orbit.

Orbital assembly operations commence by firing the CSM engines to rendezvous the spacecraft with each S-IVC stage. The IU of vehicle one is used as the astronics unit for the orbital assembly operations. The IUs for the second and third propulsive stages are jettisoned prior to docking. The CSM has primary control of the rendezvous and docking activities associated with orbital assembly. The stabilization of the orbital launch vehicle during buildup will be provided by either the attitude control subsystem on the Mars spacecraft or by RCS designs on the aft skirt of the S-IVC. Referring to Figure 3-28, the Mars spacecraft will prevent direct observations of the S-IVC stages during docking maneuvers. Indirect observation methods include:

- o Radar observation
- o TV camera
- o EVA using auxiliary propulsion
- o Combinations of above methods.

The orbital launch vehicle when assembled is checked out with CSM equipment under the direction of the Space Station. The CSM and associated docking structure is



1. IGNITE FIRST S-IVC
2. IGNITE SECOND S-IVC
3. CUTOFF SECOND S-IVC, START COAST
4. RESTART SECOND S-IVC
5. IGNITE THIRD S-IVC
6. CUTOFF THIRD S-IVC, START INTERPLANETARY COAST

Figure 3-28. S-IVC Orbit Launch Mode

Table 3-24. Experiment Payload for Mars Flyby Mission

Vehicle	Experiment Activity	Scientific Payload Weight	Gross Weight
Orbiter	Photography (Circular) Atmosphere, Particles and Fields Surface Properties	200 80	10,180
Impacters (3)	Atmospheric	48	156
Lander	Geophysics and Photography Atmospheric Sounder	125 20	1,290
MSSR	Sample Return Film Return Geophysics and Photography	2 145	11,692
Flyby Vehicle	Telescope, Film Accessories Encounter Experiments Enroute Experiments Biological Laboratory		3,670 1,457 795 1,000
Total Weight		610	30,190

0 Encounter Data - 1.0×10^{10} bits during 30 hour encounter

0 Maximum Data Rate at Encounter - 1.0×10^6 bits/sec

separated from the spacecraft just before orbital launch. Transplanetary injection is initiated by sequentially firing the three S-IVC stages and jettisoning each propulsion stage after burnout.

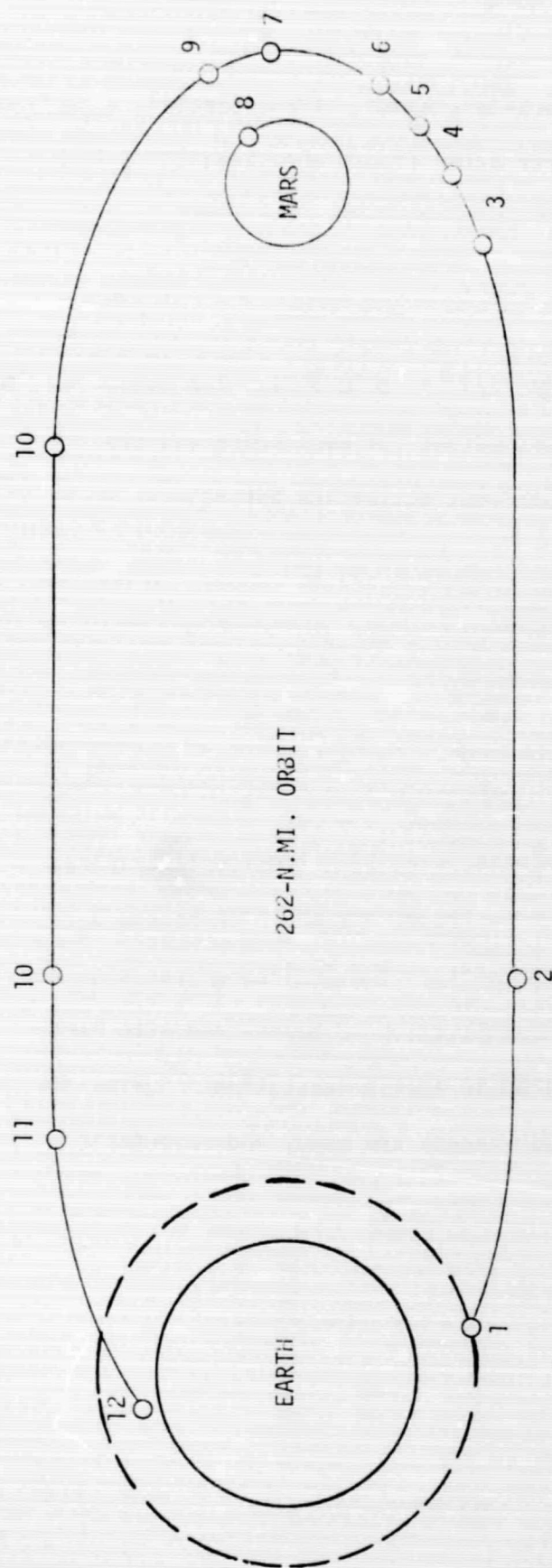
3.3.2.3 Experiment Program

The Mars Flyby experiment program¹⁰ is summarized in Table 3-24. The table shows the scientific payload weight and gross weight for each space vehicle. A brief discussion follows describing the experiment activities during:

- o Trans-Mars coast
- o Mars encounter
- o Earth return coast.

3.3.2.3.1 Trans-Mars Coast

After trans-Mars injection, the flyby spacecraft, with its experimental payload and Earth Entry Module (EEM) proceeds along the trajectory shown in Figure 3-29. Attitude control is provided as necessary to maintain the desired orientation for operational and experimental procedures. Communication is maintained with Earth through the DSIF, where tracking is maintained to assist navigation. During the trans-Mars coast, many observations and measurements are made, and scientific



1. Spacecraft injected into interplanetary trajectory from 262-n.mi. orbit.
2. First mid-course correction.
3. Inject orbiter scientific probe ten days before encounter.
4. Second mid-course correction.
5. Inject Mars surface sample return probe nine days before encounter.
6. Inject second landing probe eight days before encounter.
7. Inject aerodrag impact probes five - seven days before encounter.
8. Launch MSSR ascent stage from Mars one minute before encounter.
9. Rendezvous and sample retrieval one hour after encounter.
10. Apply Earth approach corrections.
11. Transfer to EEM.
12. Atmosphere reentry.

Figure 3-29. Typical Mission Experiment Program Profile

experiments are performed. At least one mid-course correction is made at the appropriate time as indicated by onboard trajectory computation and tracking from Earth. In addition, the probes and EEM are periodically checked out and maintenance performed as necessary.

3.3.2.3.2 Mars Encounter

During the entire approach to Mars, telescopic study of Mars atmosphere and surface is made with the 40-inch aperture telescope. At five to ten days prior to Mars encounter, probes and orbiters are launched from the flyby spacecraft. They are aimed to arrive ahead of the encounter, or closest Mars approach. The principal scientific probe is the Mars Surface Sample Return (MSSR) probe. This is injected nine days before encounter. The other science probes, Mars orbiter, geological lander, and three aerodrag impact probes, are launched in the sequence shown in the figure. At encounter, there is intensive data acquisition from the probes and observations. Measurements and photographs are taken from the spacecraft. The MSSR gathers surface samples, atmosphere samples and takes pictures. After about 1 3/4 hours on Mars surface, the samples and film are launched to rendezvous with the flyby spacecraft. The other probes transmit at high data rate to the spacecraft for up to ten days after encounter, then at lower data rates directly to Earth for six months or longer.

3.3.2.3.3 Earth Return Coast

On the return leg, portions of the Mars samples and other flyby data are analyzed, and the significant results are transmitted to Earth. In addition, experiments in solar physics and astronomy are performed beyond Mars on the far side of the Sun. The experiments such as local field strength and particle count which were conducted on the trans-Mars coast period are continued. Approach to the asteroid belt will make the meteoroid flux experiments particularly interesting. The total amount of data to be returned for the Manned Mars Flyby is estimated to be in excess of 10^{14} bits.

3.4 ONBOARD REQUIREMENTS DEFINITION

The purpose of this section is to define the functions or tasks to be performed by the Onboard Checkout and Data Management System (OCDMS) to achieve the objectives of the missions defined in Section 3.3. The importance of communication capabilities and the resulting complexities on vehicle subsystems will be stressed by analyzing two cases: 100 percent ground coverage as afforded by a data relay satellite system, and partial "on-time" coverages without the DRSS. The long distance travel for communication signals from Mars necessitated separate trades in onboard versus ground data processing considering power, bit rates, and bandwidth requirements.

The current state-of-the-art for spacecraft checkout was surveyed and used as a basis for projection to future manned mission checkout capabilities for vehicle and experiment subsystems. The spacecraft investigated included manned and unmanned vehicles. A discriminatory vehicle selection was made to best emphasize applicability of present techniques to the Space Station subsystems.

A necessary step toward establishing requirements for the OCDMS is the postulation of spacecraft subsystems which are capable of meeting the mission requirements. Electrical and mechanical subsystems were formulated to the block diagram level in sufficient detail to permit identification of test requirements. The maintenance requirements for the long duration future manned missions were considered in the subsystem study, and test points were provided to permit end-to-end testing and identification, when necessary, of malfunctioned replaceable unit. It must be emphasized that a quantitative estimate of checkout requirements and associated computer support cannot be accurately determined unless an assessment is made of the test requirements for each vehicle subsystem. Checkout analyses were,

therefore, made for each subsystem and were consistent with the predetermined repairability and maintenance levels, and the necessity for obtaining engineering/operational data relating to why or when a unit or subsystem fails.

The total data flow and the associated needs for data acquisition, processing and dissemination will determine the majority of the OCDMS requirements with added processor functions due to checkout; nevertheless, the nature of the Onboard Checkout System (OCS) demands maximum integration into the OCDMS.

3.4.1 Communications Analyses

Communication elements considered for the Space Station were:

- o Downlink, including transmitting and receiving capabilities
- o Uplink, including transmitting and receiving capabilities
- o MSFN contact time
- o Interface with data management subsystem.

Several concepts were studied including the austerity, economic and projected future standard approaches.¹ Preferred solutions are presented for the 1975-80 and 1980-85 time periods.

Maximum data acquisition period for the Mars Flyby Mission occurs at planetary encounter due to the receipt of sensor information from atmospheric probes, orbiting probes, landed probes, and spacecraft instruments. Data transmission rates to Earth are expected to be 10^6 bits/sec; therefore, data reduction and compression requirements are not critical.² Transmitting video data to Earth will severely tax the communication system even at the high data rate capability of one megabit per second.

3.4.1.1 Space Station Mission

A study was made to determine the ability of the present MSFN to handle a target estimate of 10^{10} bits/day of electronic data generated aboard the Space Station anticipated daily data rates for the Space Station range to 10^{12} ; however, this represents total data requirements and includes data which will be returned to the ground on film. The ground coverage time for a 270 nm, 50° inclination orbit is shown in Figure 3-30 for each orbit. The "on-time" per day from this figure results in the following average data rates to transmit 10^{10} bits per day to the ground:

<u>Number of MSFN Ground Stations</u>	<u>Required Average Data Rates</u>
16	265K bits/sec
5	925K bits/sec

Achievement of the above data rates appears feasible by redesign and modification of the present USB. A potential data rate of 8.5×10^6 bits/sec can be attained within the USB bandwidth allocation by improving bandwidth utilization.¹ Thus, with modifications to the existing USB, 10^{10} to 10^{12} bits/day can be transmitted to the MSFN ground stations without a Data Relay Satellite System (DRSS). It is anticipated that it would be difficult to transfer this amount of information to a central computing complex such as RTCC, Houston in real-or near real-time. A data relay satellite system offers a potential advantage over use of the MSFN in that continuous communications coverage can be provided for the Space Station.

A summary of the major advantages to be realized with a DRSS are:

- o Reduction in direct data transmission rates from the Space Station to ground

NOTES: 270 N.M. CIRCULAR ORBIT
 50° INCLINATION
 16 STATIONS —
 5 STATIONS —

	16 STATIONS	5 STATIONS
MAX TIME/ORBIT (MINS.)	65	29
MIN TIME/ORBIT (MINS.)	4	0
APPROX. TIME/DAY (HRS.)	10.5	3

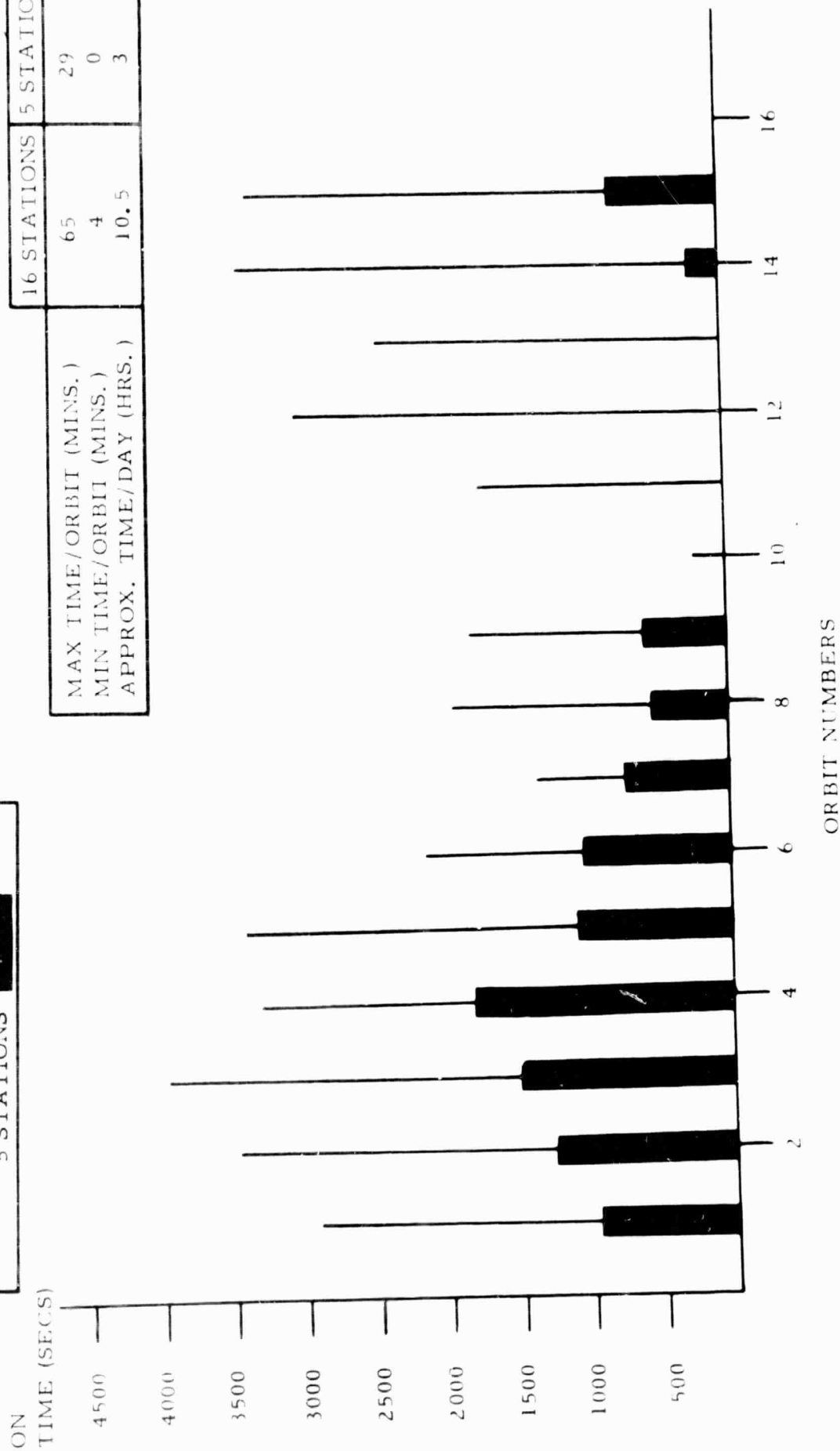


Figure 3-30. Space Station to Ground Station Coverage (On Time Per Orbit)

- o Reduction in number of MSFN stations
- o Decreased out-of-contact time
- o Possible simplification in retrieval of bulk data from remote ground stations to a central processing facility.

A comprehensive study of the onboard-to-ground and ground-to-ground data handling capabilities and costs must be made to establish the minimum cost data handling configuration.

3.4.1.1.1 Communication Link Impacts upon Space Station Checkout

Investigation of the Space Station-to-ground communications link does not provide clear insight to the constraints imposed on ground-augmented checkout of onboard systems. It will be feasible to dump the checkout data from the Space Station to the ground. However, large amounts of data generally would not be available to a central checkout complex such as MCC Houston or KSC in real-time. Analysis of the ground-to-ground communications links are required to establish realistic delays in data retrieval to a central location for various system configurations of ground stations and relay satellites. Additionally, computation constraints at the central checkout center must be considered in bounding the amount of checkout data which can be processed and evaluated.

General recommendations which may be made on the basis of communications analysis regarding checkout are as follows:

- o Onboard systems, which are mission critical and require real-time response, must be monitored and checked out onboard to achieve the required degree of autonomy for Space Station systems checkout.

- o Onboard processing capability may be used in support of systems checkout rather than experiment data processing. Some tradeoff between the two must eventually be made. Experiment bulk data may generally be evaluated more comprehensively on the ground than by the onboard computer. Further, real-time evaluation of experiment data does not carry with it the priority that real-time evaluation of checkout data does.
- o The previous recommendation does not preclude onboard processing of experiment data. A trade must be made to evaluate the relative costs of onboard processing versus communications system modifications necessary to dump bulk experiment data to ground. The essential point is that first priority for available processing capability should be allocated to onboard checkout. There are no known technological barriers to providing the communications capability to transmit most of the experiment data to ground. There may well be immutable constraints on the timely retrieval of vehicle data to a central location to allow ground-controlled checkout of onboard systems.

NASA's interest in the field of communications includes not only development of systems required for peaceful exploration of space but also the development of communications technology required by COMSAT and INTELSAT, private/corporate agencies, and for Government agencies. The Applications Technology Satellite (ATS) series has and will continue to be the vehicle for packing NASA's communications technology. For example, it is anticipated that later technology satellite flights will deploy 30-foot or larger diameter parabolic antennas after achieving synchronous orbit.⁹ The communication links discussed in this section for the 1975-80, 1980-85, and post-1985 periods are based on the technology expected to

be operational for the given time frame. Optical communication links are not expected to have the proven reliability for manned missions before 1980 and are, therefore, not recommended for 1975-80 time period. The pacing technology requirements for each time frame will be discussed in the corresponding preferred communication link concept for that period.

3.4.1.1.2 Preferred Communications Link Concept 1975-80

The best solution for the 1975-80 period appears to be a system consisting of:

- o Two ground stations (Houston and Alaska)
- o Two delayed repeater satellites in low altitude elliptical orbit
- o A round-the-clock voice circuit and/or 5000 bps data link via commercial COMSAT
- o An HF emergency link.

This system could handle 10^{11} bits per day without difficulty, and this would be improved to 10^{12} bits after further development of variable rate modulation and coding systems. The maximum delay for high rate information would be 90 to 120 minutes.

The cost of such a system would be around \$20M initially and \$10M annually for operation (including replacements).

3.4.1.1.3 Preferred Communication Link Concept 1980-85

A system consisting of two geosynchronous NASA owned communications satellites, using the same two ground stations as previously discussed but with less costly antennas, would be the most attractive solution for the 1980-85 period. The

voice circuit backup via COMSAT will be used for the 20 minutes per orbit when the Space Station is out of sight of the geosynchronous satellites. An HF emergency link will also be used. This system would have a capability of handling 10^{11} bits per day with a maximum transmission delay of 20 minutes and with real-time, high-rate information transmission capability during nearly 2/3 of each orbit. The initial cost (including satellite development) might be \$80M with about \$15 annual operation cost.

3.4.1.1.4 Preferred Communication Link Concept after 1985

The ideal solution of the DRSS problem would be a permanent system of four satellites in geosynchronous orbits about 90° apart. The stations (COMSAT) should be available to all satellites of all nations, and ground stations might be operated by different nations. Each satellite will have high capacity links (most likely optical links to the two neighbor stations). One may speculate that electronically steerable antennas (or telescopes) of extremely high gain (60 to 80 db) could pin-point instantaneously any spacecraft needing communications. This pin-pointing would be done at the request of the spacecraft either in quasi-synchronous repetition mode (for high transmission rates) or in asynchronous quasi-random access mode (for low transmission rates.)

"Quasi-synchronous repetition" means that the COMSAT will interrogate the spacecraft at regular intervals (synchronously), yet in such a way that the precise instant of the beginning of a new transmission interval will be scheduled to pin-point the electronically steerable antenna to the satellite exactly over the duration of the arrival of the signals at the COMSAT. Remember that the transmission delay of the signals from a spacecraft in a low altitude orbit to the COMSAT is in the order of 130 msec. The COMSAT may operate with 100 mhz bandwidth and with instantaneous data rates of 500 megabits per second; this

means a transmission word of 500 bits will last only 1 μ sec. The time of arrival of such words has to be computed very accurately, and the beam switching has to be very precise. The average repetition rate of such 500 bit words will depend on the information rate to be transferred. For picture transmission (after redundancy reduction) there would be about 10,000 to 20,000 words per second and for voice transmission, approximately 10 to 100 words per second.

"Quasi-random access mode" means that any participating spacecraft would have access to the transmission system after the minimum delay time needed for requesting the access (including a small scheduling delay). A telemetry data transmission would take place in 500 bit words whenever a word has been assembled. No transmission takes place when the sensors do not offer essential information. As soon as a word is assembled, this fact is reported to the COMSAT via a special small band (or completely random access) channel, and the COMSAT will interrogate the spacecraft depending on the transmission arrival schedule that is continuously programmed in its computer.

This future standard system will have such a high capability that very simple equipment with low gain antennas will suffice for the spacecraft terminals. No transmission capacity will be wasted during idle times, and maximum capacity will be made available in real-time when required. This adaptive asynchronous operation will increase the efficiency of a DRSS for several orders of magnitude.

The COMSAT network will be resupplied and serviced by manned logistics vehicles. The technology required for the realization of this COMSAT network will have to be developed during the 1975-85 phases of the Space Station program. The cost of this system is difficult to estimate; however, it may be anticipated to be comparable to the cost of the present MSFN.

3.4.1.1.5 Cost Comparisons for Candidate Communication Links

The initial cost for the MSFN (including ships and aircraft but excluding 85 foot antenna stations) was \$306M, and the yearly operational costs, including replacements, are \$73.3M.³ The costs for the MSFN and the preferred communications concepts for the 1975-85 period are plotted in Figure 3-31. Over the ten year mission period, the costs for the preferred concepts are significantly less due to lowered ground operational costs.

3.4.1.1.6 Conclusions

The following conclusions are made:

- o The MSFN (as it now exists) is a very costly and a rather inefficient solution to the information transfer problem.
- o A geosynchronous DRSS requires further technological progress before it will be acceptable as an efficient and economical solution. A wideband (4 MHz) GS-DRSS is not likely to be operational before 1980.
- o The presently available solutions have a wide margin in the tradeoff between systems cost and delivery delay of wideband information (pictures, extremely high data rates). If a maximum delay of 12 hours is tolerable in the transfer of wideband information from the Space Station to Houston, very economical solutions appear feasible. If this maximum tolerable delay is only about 20 minutes, the total systems cost is ten times higher than for the 12 hours tolerable delay.

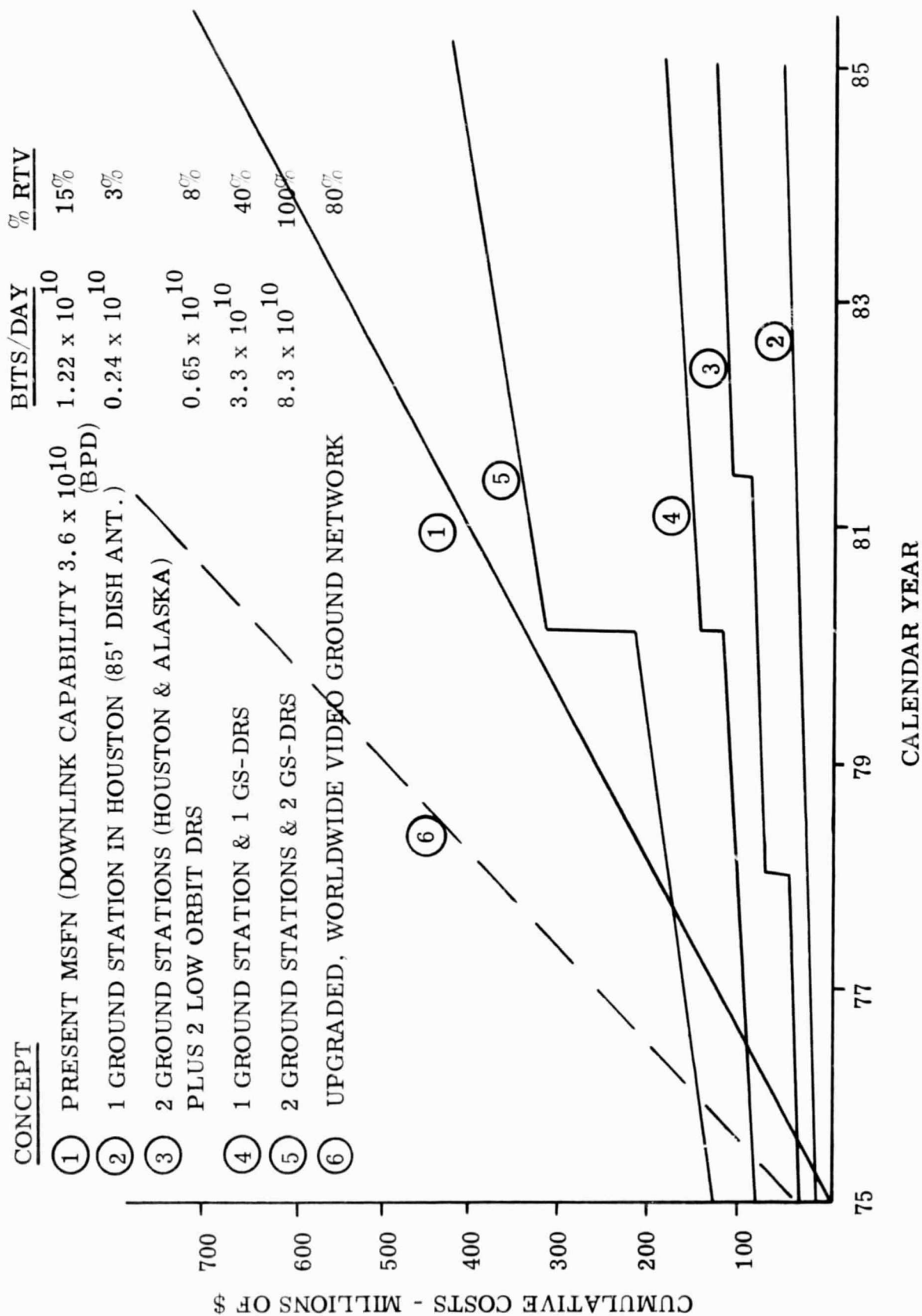


Figure 3-31. Comparative Costs for Candidate Communications Links

- o A round-the-clock real-time wideband capability is not within the range of the present technology, not even after a costly upgrading of the MSFN. It may be possible to provide such a capability by 1980 (at very high cost) and by 1985 (at moderate cost).
- o A round-the-clock real-time low rate capability (5000 bps) appears feasible by 1975, with the help of a modified commercial GS-DRSS, at relatively low cost.

3.4.1.2 Manned Interplanetary Flyby Mission - Communication Considerations

The communications systems for an interplanetary mission was investigated. Video data will constitute approximately 98 percent of the experimental data required by the interplanetary probe.⁴ Transmitting video data to Earth will severely tax the communications system even when considering the probable maximum realizable capability of 10^6 bit/sec.² Detailed quantitative requirements for the video transmissions have not been made. It is assumed that a PCM video transmission system will be employed. Two key parameters determine the digital data required for transmission of video or graphic data: frame resolution and quantization level of picture element contrasts (both being related to the quality of the image received on the ground). For medium quality video, a frame resolution of 10^6 picture elements per frame is likely required. Each picture element may require 30 levels of contrast for observation of adequate detail. This requirement dictates 5 bits for encoding of the intensity level times 10^6 elements per frame or 5×10^6 digital bits per frame just to digitally represent an image. Transmission of a frame will require additional tag and address bits resulting in approximately 10^7 bits per frame for transmission of medium quality television pictures. Clearly, less than one frame/sec may be

transmitted to Earth with the 10^6 bits/sec communications system. A tradeoff must be made to establish the quality of pictures transmitted and the frame rate at which certain data will be transmitted. The point to be made here is simply that experiment video data requirements can easily use up the entire transmission capability of the communications system, leaving very little capacity available for transmission of vehicle checkout data except on an emergency or contingency basis.

Significant Earth participation in checkout of the interplanetary vehicle is precluded by several factors. As indicated in Figure 3-32, communications delays as long as one hour occur for two-way transmissions during the deep space portions of the mission. Real-time or near real-time ground response to spacecraft activity is not possible under these conditions. Continuous monitoring of vehicle parameters by the ground is desirable for mission evaluation; however, for strictly checkout purposes (implying detection of an anomaly and initiation of some remedial measure), the ground cannot react in time to be placed in the checkout loop for mission critical functions.

The amount of coverage time provided between ground and spacecraft during the interplanetary mission is also of importance. The data rate capabilities alluded to earlier presume reception of spacecraft transmission by the 210 foot diameter antenna on earth. Presently, the DSIF includes only one antenna of this size; this limits coverage at higher data rates to approximately 30 percent of the time. Further, the higher data rates projected (10^5 - 10^6 bits/sec) presume a receiver noise temperature of 50°K . This figure is appropriate for the situation where the ground antenna is directed at a low noise region in space. Should the ground antenna point near the vicinity of the solar disk, the noise temperature could go as high as $50,000^\circ\text{K}$. This situation causes a virtual communications

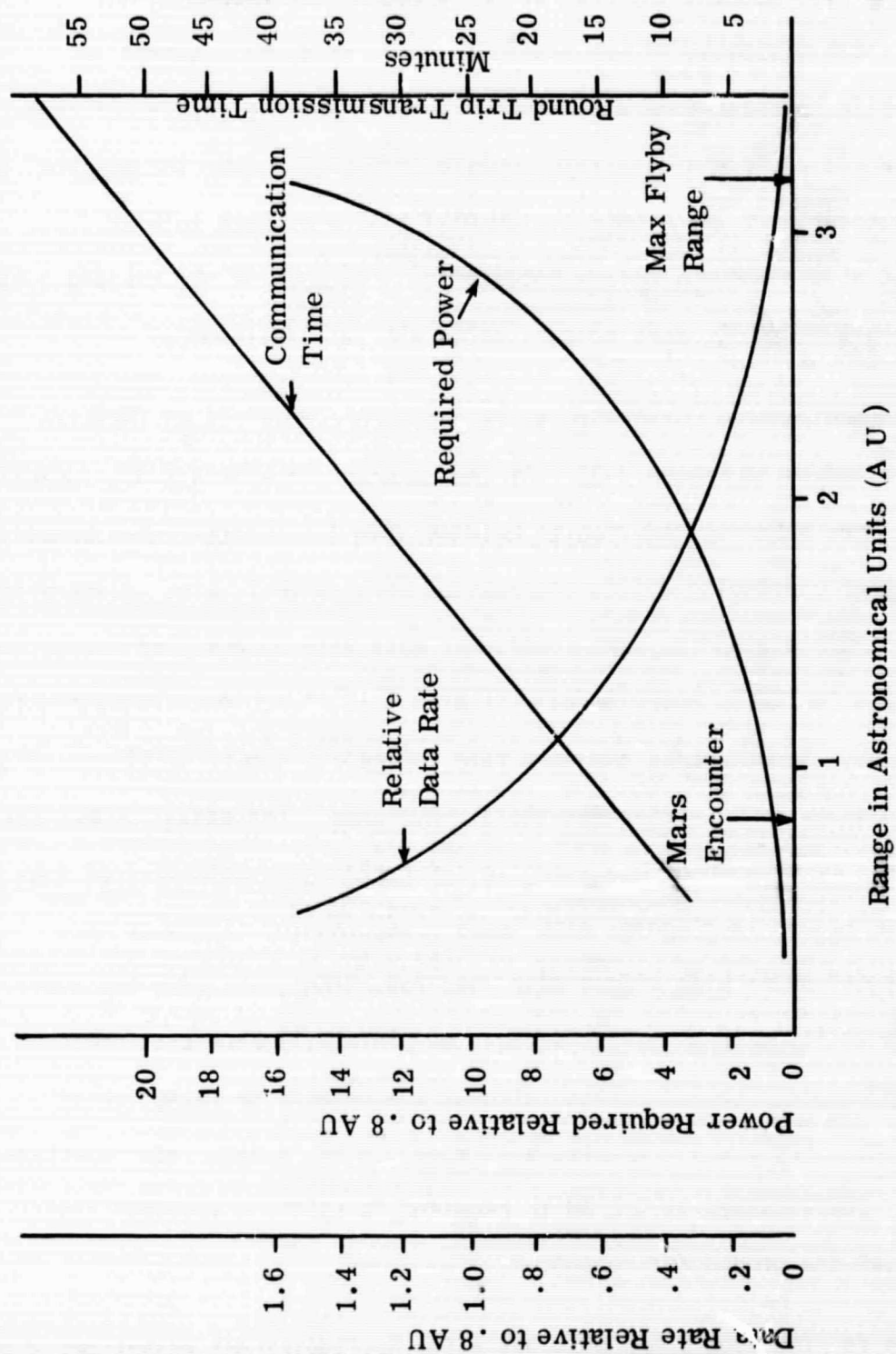


Figure 3-32. Communications System Parameter Variation with Range for Mars Flyby Mission

blackout as the sensitive receiver equipment cannot withstand pointing directly at the sun. Thus, 100 percent coverage of the probe by the ground at the communications rates discussed is not possible. More study is required to establish realistic coverage time estimates. Even without the results of these studies, which would produce a data rate profile versus time over the mission duration, it is clear that the ground system will play a minimum role in onboard checkout of the interplanetary spacecraft. Checkout of the onboard systems, after parking orbit assembly, must be considered virtually autonomous.

Assessment of communications capability at ranges larger than 0.8 AU (Martian encounter) is reflected in Figure 3-32. At the maximum range of 3.2 AU, approximately 16 times more power is required to maintain the 0.8 AU data rate capability. An alternate way of expressing system degradation with range is also illustrated in Figure 3-32. Maintaining the same power, the data rate capacity of the system must decrease by a factor of approximately 16 at 3.2 AU to achieve the same data rates as at 0.8 AU. Reduction of the data rate represents a more viable solution to maintaining quality communication at the 3.2 AU range. The actual communications systems must be capable of operating in different modes with several sub-carriers for the various incremental data loads. Suppression of one or more modes at the larger ranges will effect data load reductions, allowing the available power to be utilized in a smaller bandwidth. This will have the effect of maintaining an adequate signal-to-noise ratio at the ground for reception of reduced data rates. For the 10^6 bit/sec system at 0.8 AU, a data rate reduction to approximately 50K bits/sec at 3.2 AU is required to maintain adequate signal-to-noise ratios at the ground for reception.

Relay satellites for the deep space missions offer no significant advantages when benefits are weighed against the costs and technological problems attendant to their operation. Large antennas, high power requirements, large launch weights,

and severe attitude control accuracy constraints generally characterize a relay satellite supporting a deep space mission.⁵ The potential gain to be realized is increased coverage time with some possibility of slightly increased data rates. It appears that installation of a second ground-based 210 foot diameter antenna represents a better solution.

Optical communications systems, while potentially offering higher data rates than RF systems for comparable power and weight, are presently in the conceptual stage only. Should an early optical system be developed during the flyby mission time frame, the data rate capability of the system will be comparable to the 10^6 bits/sec RF system discussed earlier.⁶

3.4.2 Space Station/Base Requirements

An analysis was made of the Space Station vehicle and experiments subsystems to establish their operational and test requirements. The results of the analyses were used to establish the requirements for the Onboard Checkout and Data Management Subsystem (OCDMS).

There will exist numerous complex interfaces with the Space Station, and all were studied because of their influence on the Space Station OCDMS. As shown on Figure 3-33, the Space Station will, during its lifetime, be in direct contact or in the proximity of the launch vehicle, logistics vehicle, orbital tug, experiment modules and GSE. The initiation or startup operations for all modules will be controlled by the Space Station's OCDMS; subsequent operations will be controlled by the module's Onboard Checkout Subsystem (LCS) with status data transmitted to the Space Station's OCDMS. The importance of the man/machine interface (see Figure 3-34) becomes evident because the Space Station is required to support the operations of all program elements which will be frequently modified or replaced during the ten-year mission.

The OCDMS requirements are summarized in Table 3-25 for the Space Station. Even though orbital operations should have the highest priority when designing the OCDMS, the factory and prelaunch testing requirements must be considered to achieve equipment commonality in testing for all mission phases. The interrelationship between reliability, maintenance and checkout is depicted in Figure 3-35. Checkout levels are closely related to maintenance levels because it becomes necessary to identify through test the malfunctioned replaceable unit. The

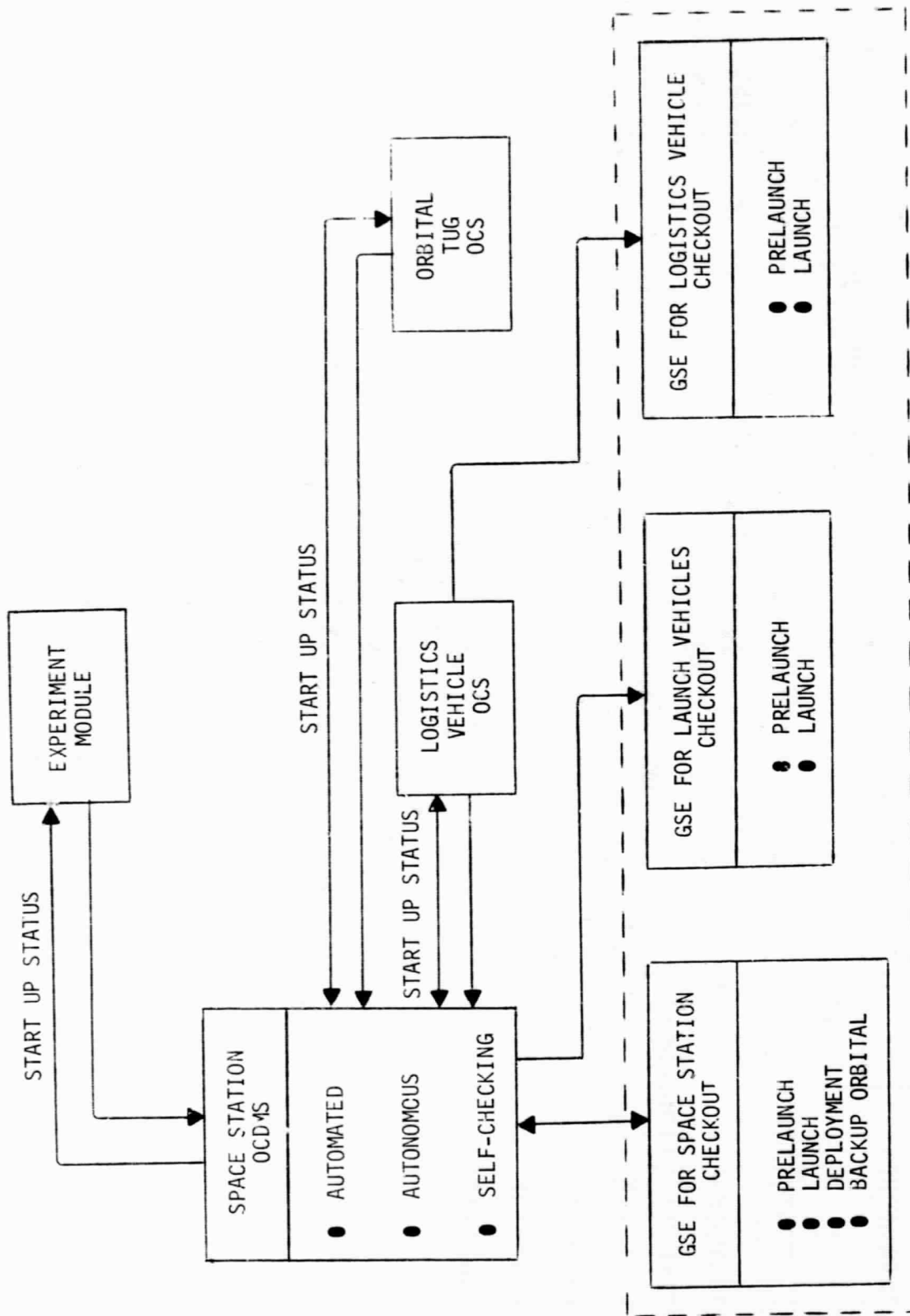


Figure 3-33. Checkout Interfaces for Space Station Program

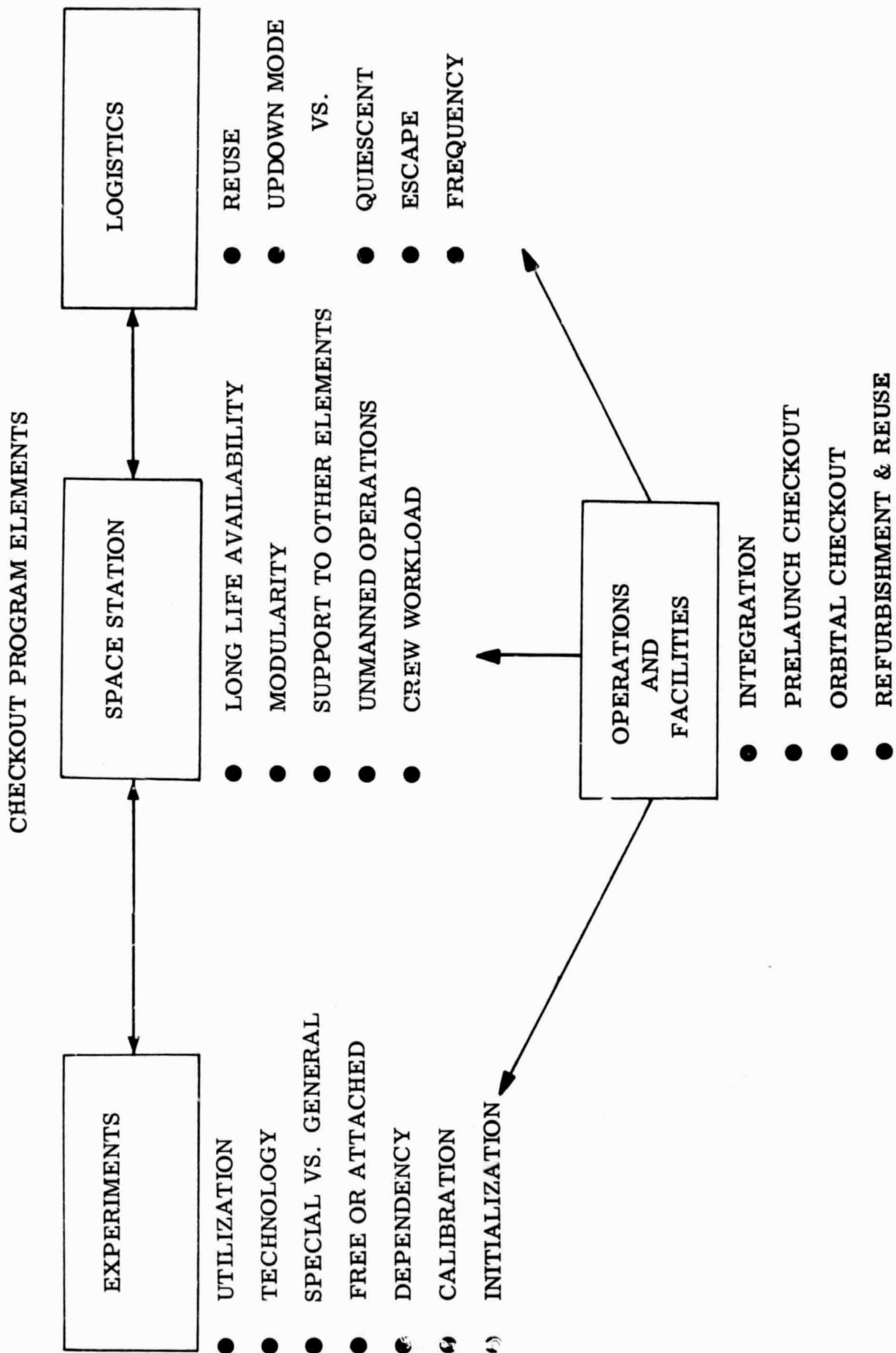


Figure 3-34. Program Elements for Space Station Checkout

Table 3-25. OCDMS Requirements for Space Station

<u>KEY POINTS:</u>	<u>TASKS:</u>
● Space Station OCDMS must be compatible with all interfacing program elements ● Orbital operations have first priority on OCDMS design ● OCDMS capabilities will be used to minimize prelaunch testing time and manpower requirements ● Checkout requirements must be defined for conceptual subsystems ● Checkout requirements and techniques vary from subsystem to subsystem ● Reliability, maintainability and system failure effects are interrelated	● Select representative subsystems to satisfy mission requirements ● Determine subsystem maintenance and checkout levels ● Determine the checkout approach for each subsystem type ● Estimate checkout requirement for: - Electronic subsystems - Vehicular subsystems - Experiments - Prelaunch ● Estimate computer processor requirements for the checkout requirements: - Memory - Operations/second

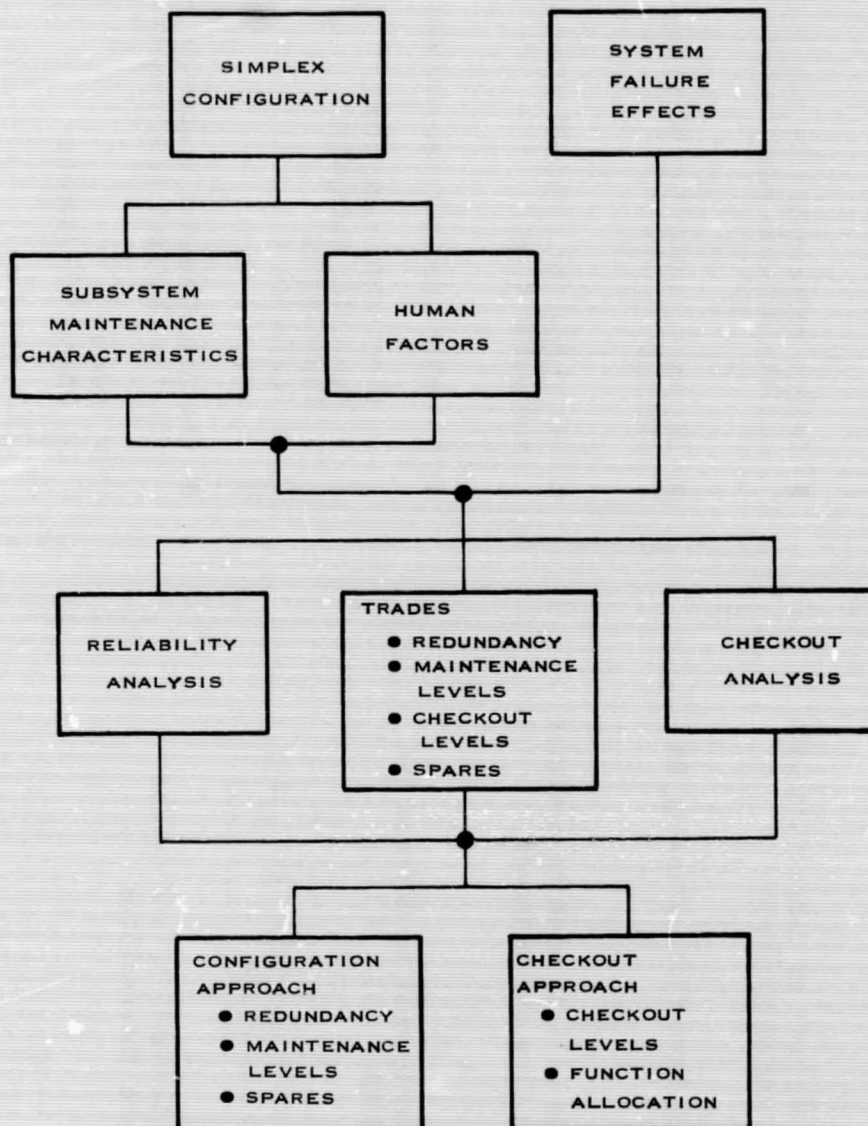


Figure 3-35. Reliability, Maintainability, & Checkout Relationships

necessity for maintenance for long life Space Station components is shown in Figure 3-36. The abscissa is a plot of the reliability exponent λt , where λ is the component failure rate and t is mission time. The exponential failure law is $R=e^{-\lambda t}$, where R is the reliability or probability of successful operation for the time t . The elliptical regions for the inertial gyro, digital computer and CMG represent current reliabilities for the Space Station mission, and it is evident that not only is maintenance required, but components with high failure rates will require greater number of spares. The sparing requirement for a computer system with an MTBF = 10^4 hours is shown in Table 3-26 for varying reliability goals and operating life times. Rate gyro reliability improvements, with redundancy and spares, are shown in Figure 3-37. Only curve A for three operating gyros and six standby gyros is considered acceptable for the two year Space Station mission's reliability requirements. Table 3-27 shows the initial and final reliabilities for the Space Station subsystems based upon redundancy and spare usage.⁹ The added weights required to achieve 0.99 probability of mission success (Table 3-28) are: 6,631 lbs. redundant weight and 8,820 lbs. spares weight for a total added weight of 15,451 lbs.

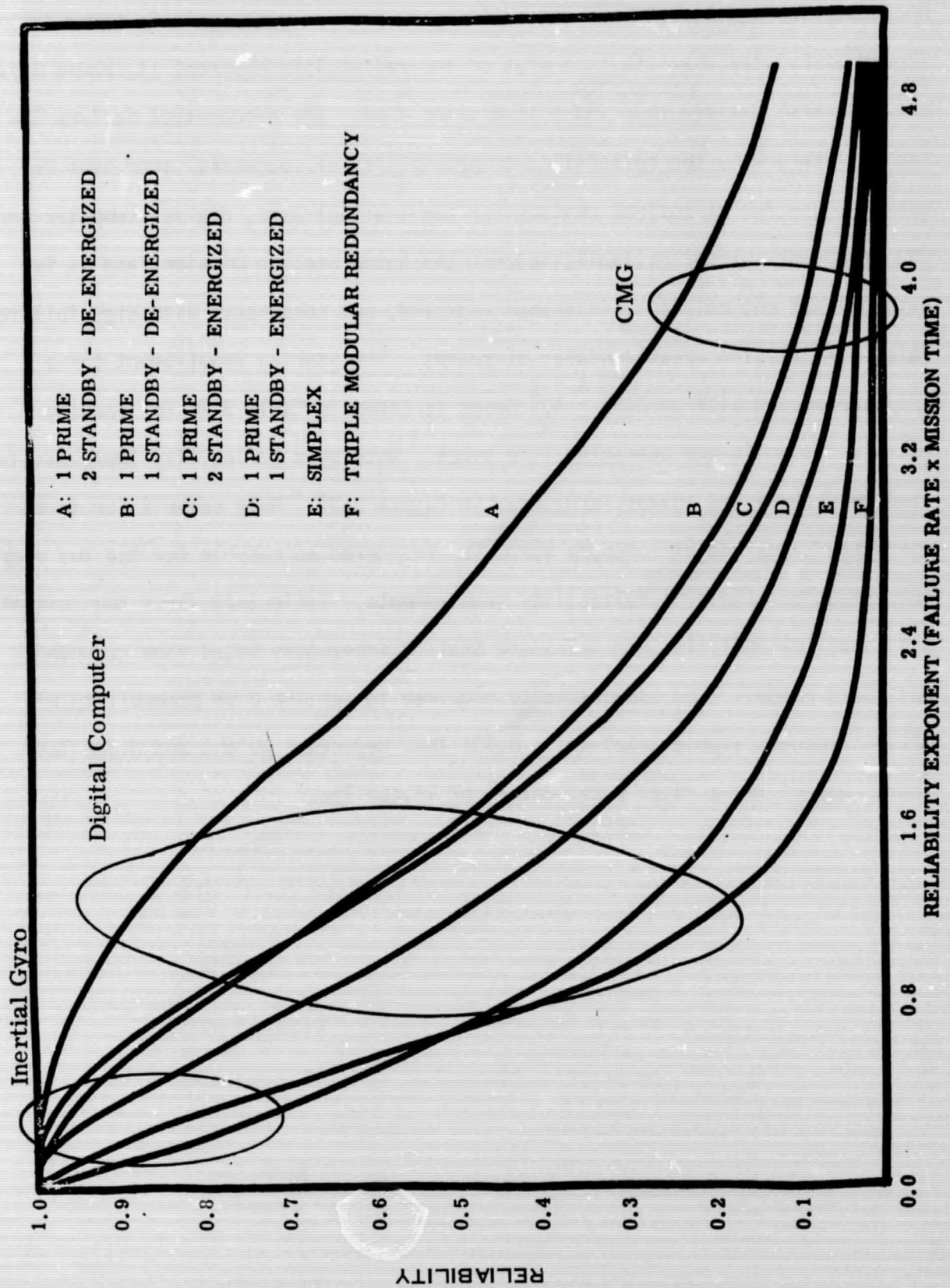


Figure 3-36. Relative Merits of Redundancy Schemes

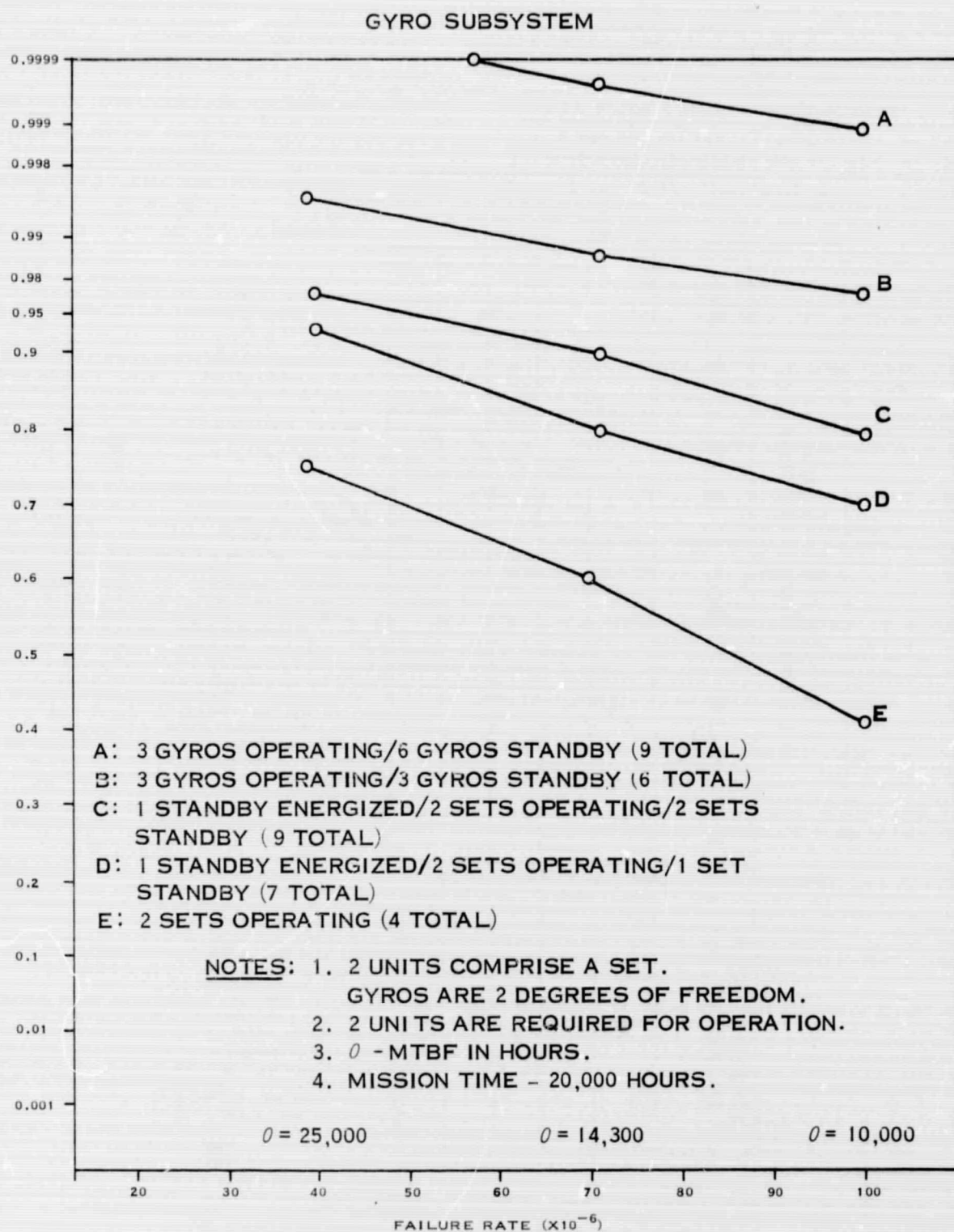


Figure 3-37. Rate Gyro Reliability

Table 3-26. Spares Required for Given Reliability Goals

Computer System Reliability Goal R_T	Operating Time (hours) (Assuming $MTBF_S = 10^4$ hours)				
	2000	5000	7000	10,000	20,000
0.99	2	3	3	4	6
0.95	1	2	2	3	5
0.90	1	1	2	2	4
0.85	1	1	2	2	3
0.80	0	1	1	2	3

Table 3-27. Improvement in Space Station Reliability
Using Redundancies and Spares

Subsystem	.99 Reliability for 730 Days	
	Initial	Final
Communications and Data Management	2.4×10^{-7}	.99931
Crew System	1.1×10^{-5}	.99942
Electrical Power	4.9×10^{-2}	.99839
Inflight Test	1.2×10^{-5}	.99983
EC/LSS	7.7×10^{-11}	.99599
Maintenance Equipment	9.4×10^{-1}	.99996
Propulsion	2.3×10^{-2}	.99812
Guidance and Control	2.5×10^{-4}	.99899
All Subsystems	6.47×10^{-34}	.99004

Table 3-28. Redundancies and Spares Weights
for Space Station Subsystems

Subsystem	Initial (Lbs.)	Redundancy (Lbs.)	Spares (Lbs.)	Total Added (Lbs.)
Communications and Data Management	1,559	150	1,259	1,409
Crew System	19,914	0	859	859
Electrical Power	11,835	755	2,215	2,970
Inflight Test	294	0	373	373
EC/LSS	41,789	4,540	2,358	6,898
Maintenance Equipment	62	0	41	41
Propulsion	10,943	233	12	245
Guidance and Control	5,502	953	1,703	2,656
Total	91,898	6,631	8,820	15,451

3.4.3 Vehicle Subsystem Inflight Checkout Requirements

A number of representative Space Station vehicle subsystem concepts were developed in the course of the study. The test requirements for one of the most significant subsystems (Guidance, Navigation and Control) will now be identified to illustrate the analysis methodology. The depth of the analyses was necessarily limited because the subsystem concepts must be considered preliminary and only representative of expected Space Station designs. The analyses approach was:

- o Establish representative subsystem concepts considering performance and availability requirements.
- o Perform functional analysis to identify hardware required to implement system tasks.
- o Perform failure mode effects and criticality analyses to assist in identification of checkout requirements.
- o Establish logic routines and test modes for monitoring and fault isolation analyses.
- o Determine requirements for test measurements.
- o Perform failure analyses and estimate required test measurements.

The rationale for establishing the test measurements needed for each subsystem is shown on Table 3-29. The status monitoring test measurements are end-to-end testing requirements wherein higher level test measurements are monitored to assess performance and further testing resorted to only when a no-go is indicated. Operational capabilities will be used for test whenever possible to reduce testing complexities; this type of integrated testing should also provide maximum performance data with minimum testing. Integrated testing, by determining whether system operational functions are properly carried out, will permit restructuring into alternate operational modes when necessary. Test measurements must be provided to identify subsystem

Table 3-29. Subsystem Checkout Requirements as a Function of Increasing Test Complexity

Test Complexity	Subsystem Performance Verification
(1) Status Monitor	Provide all required test measurements
(2) Integrated Testing	(1) Plus provide test measurements for maximum performance with minimum testing
(3) Restructuring (Operation in Alternate Modes)	(2) Plus establish alternate operational modes and associated test measurements
(4) Fault Prediction	(3) Plus provide all subsystem failure signatures for trend analysis and replaceable unit identification

failures, thereby permitting identification of replaceable malfunctioned units and establishing trends for use in failure prediction.

An important design aspect for all subsystems will be ease of maintainability. Certain scheduled maintenance procedures may be required and can be preplanned to coincide with normal logistic resupplies. Component or assembly malfunctions are unpredictable necessitating unscheduled maintenance activities. The onboard checkout subsystem must quickly pinpoint the malfunctioning hardware to the replaceable level thereby expediting corrective actions. This will maximize system availability while minimizing the time that crew members are detained from scheduled activities.

The test measurement requirements for the Space Station depends on the design concepts chosen for the individual subsystems. Satisfactory identification of the test requirements demands a close working relationship between the vehicle and experiment subsystem designers and the OCDMS designers. Because of its important role in checkout, the onboard computer functional requirements must be considered during the earliest subsystem conceptual design stages. The primary objectives are:

- o Maximize OCDMS capability to fully evaluate performance to the component level
- o Minimize hardware and software complexities
- o Minimize amount of time astronaut and ground crews must participate in checkout.

3.4.3.1 Guidance, Navigation and Control Sensor Subsystem

Maintenance characteristics for the GNC sensors are summarized in Table 3-30. Spares for the replaceable units are identified together with the installed redundancies necessary to achieve the desirable reliabilities.

Table 3-30. Maintenance Characteristics - GNC Sensors

Devices	Maintenance/Redundancy
Gyro Package Gyros Electronics	Installed redundancy + limited spares. Alignment by mechanical fit Spares - Alignment by mechanical fit SRU spares Note: Gyros and electronics calibration constants are predetermined
Rate/Attitude Computer	Built-in redundancy - PRU and SRU spares
Horizon Sensor Heads	Installed redundancy, failure mode operation, no in-flight maintenance
Horizon Sensor Electronics	PRU and SRU spares
Star Tracker Optics Assembly	Failure mode operation - no in-flight maintenance
Star Tracker Electronics	PRU and SRU spares

Note. PRU - Primary Replaceable Unit
SRU - Secondary Replaceable Unit

The horizon sensor assembly is composed of eight scanner heads and two processor boxes. One horizon scanner channel, block diagrammed in Figure 3-38, is associated with each scanner head. Table 3-31 presents a summary and description of measurements needed to perform checkout of a single horizon scanner channel. The test points shown in the figure are marked as follows:

- o Triangles (Δ) indicate "active" test points requiring external stimuli for test.
- o Circles ($\circ$) indicate passive test points where only operational signals are required for testing purposes.

The star tracker assembly consists of two star tracker units. A block diagram of a single star tracker unit showing the test points required for checkout appears as Figure 3-39. A summary and description of test measurements (Table 3-32) shows what is required for checkout of a star tracker unit.

3.4.3.2 Solar Sensor Assembly

The solar sensor assembly is comprised of four sensor heads and four processor channels. A block diagram of a single channel showing checkout requirements is given for Figure 3-40. A summary and description of measurements required for checkout is presented in Table 3-33.

3.4.3.3 Gyro-Inertial Attitude Reference Assembly

Three gyro packages and three rate/attitude computer units comprise the gyro-inertial attitude reference assembly. Block diagrams of these devices showing checkout requirements are shown in Figure 3-41 and 3-42. Summaries and descriptions of test measurements required for checkout of these units are given in Tables 3-34 and 3-35.



3-38. Horizon Scanner Onboard Test Points

Table 3-31. Summary of Test Measurements Required for Checkout of One Horizon Scanner
(8 Scanners Required)

Test Point Number	Function	Signal Type	Parameters of Interest
HS-1	Sample and Hold Output	DC Voltage	Voltage Level
HS-2	Amplifier Output	Pulse Train	Peak and RMS Voltage
HS-3	Time Threshold Output	Pulse Train	Peak and RMS Voltage
HS-4	Threshold Detection Output	Pulse Train	Peak and RMS Voltage
HS-5	Clock Output	Pulse Train	Peak and RMS Voltage and Frequency
HS-6	Buffer Output	10 Bit Word	Value
HS-7	Power Converter Monitor	Discrete	

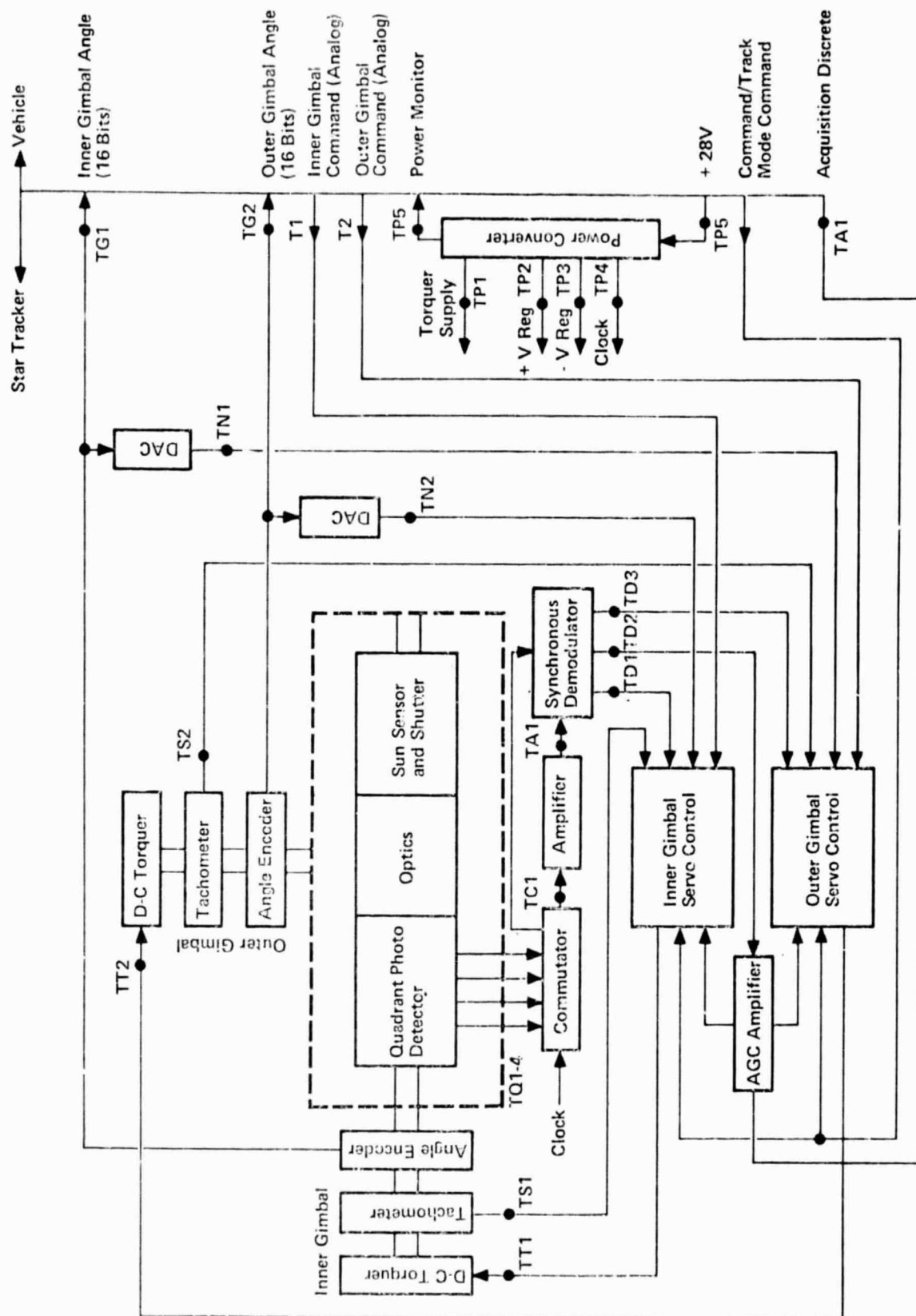


Figure 3-39. Star Tracker Onboard Test Points

Table 3-32. Test Measurements Required for Checkout of One Star Tracker Unit
(2 Units Required)

Test Points	Function	Signal Type	Parameters of Interest
TG1 - TG2*	Gimbal Angles	16 Bit Digital Word	Numerical Value
T1 - T2*	Gimbal Angle Commands	Analog Voltage proportional to desired Gimbal Angle	Voltage Levels
TP1	Torquer Voltage	DC Voltage	Voltage Level
TP2 - TP3	±DC Supply	DC Voltage	Voltage Level
TP4	Clock	Square Wave	Amplitude and Frequency
TP5	+38V Supply	DC Voltage	Voltage Level
TP6	Power Monitor	Discrete	
TA1	Acquisition	Discrete	
TH1 - TH2	DAC Output	Analog Voltage	Voltage Level
TD1 - TD5	Demod Output	Analog Voltage	Voltage Level
TC1	Commutator Output	PAM Train	Pulse Amplitude

*End-to-end test points

Table 3-32. Test Measurements Required for Checkout of One Star Tracker Unit - Cont.
(2 Units Required)

Test Points	Function	Signal Type	Parameters of Interest
TA1	Amplifier Output	PAM Train	Pulse Amplitude
TQ1 - TQ4*	Commutator Input	Analog Voltage	Voltage Amplitude
TT1 - TT2	Torquer Input	Analog Current	Current Level
TS1 - TS2	Tach, Output	Analog Voltage	Voltage Level

*End-to-end test points

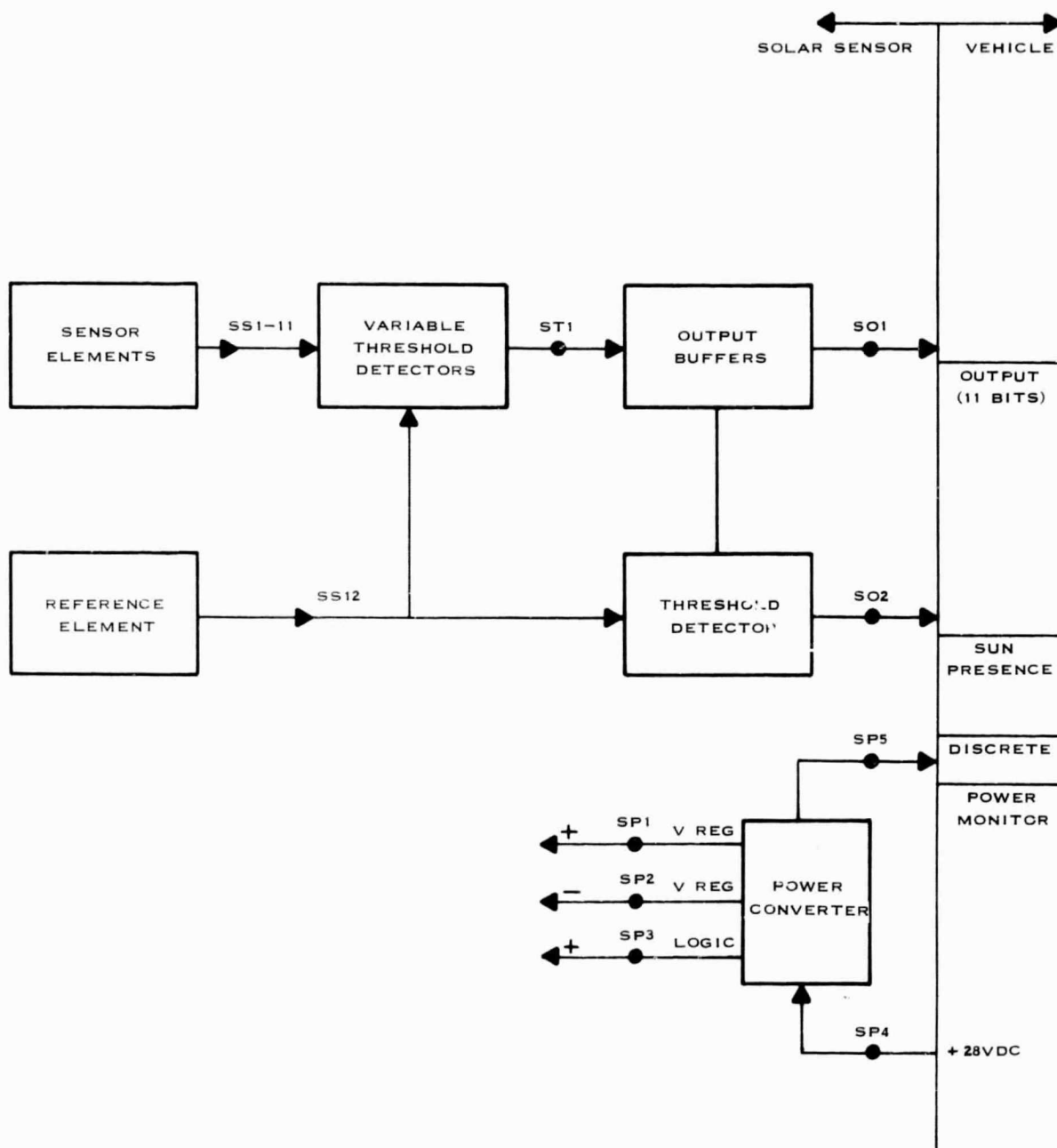


Figure 3-40. Rate/Attitude Computer Onboard Test Points

Table 3-33. Test Measurements Required for Checkout of One Solar Sensor Channel
(4 Channels Required)

Test Points	Function	Signal Type	Parameters of Interest
SS1 - SS12 *	Solar Sensor Outputs	Analog Voltage	Voltage Level
ST1	Threshold Detector Outputs	11 Bit Digital Word	Numerical Value
S01	Output Data	11 Bit Digital Word	Numerical Value
S02	Acquisition Discrete	Discrete	
SP1 - SP3	DC Supply	DC Voltage	Voltage Level
SP4	28 VDC Supply	DC Voltage	Voltage Level
SP5	Power Monitor	Discrete	

*End-to-end test points

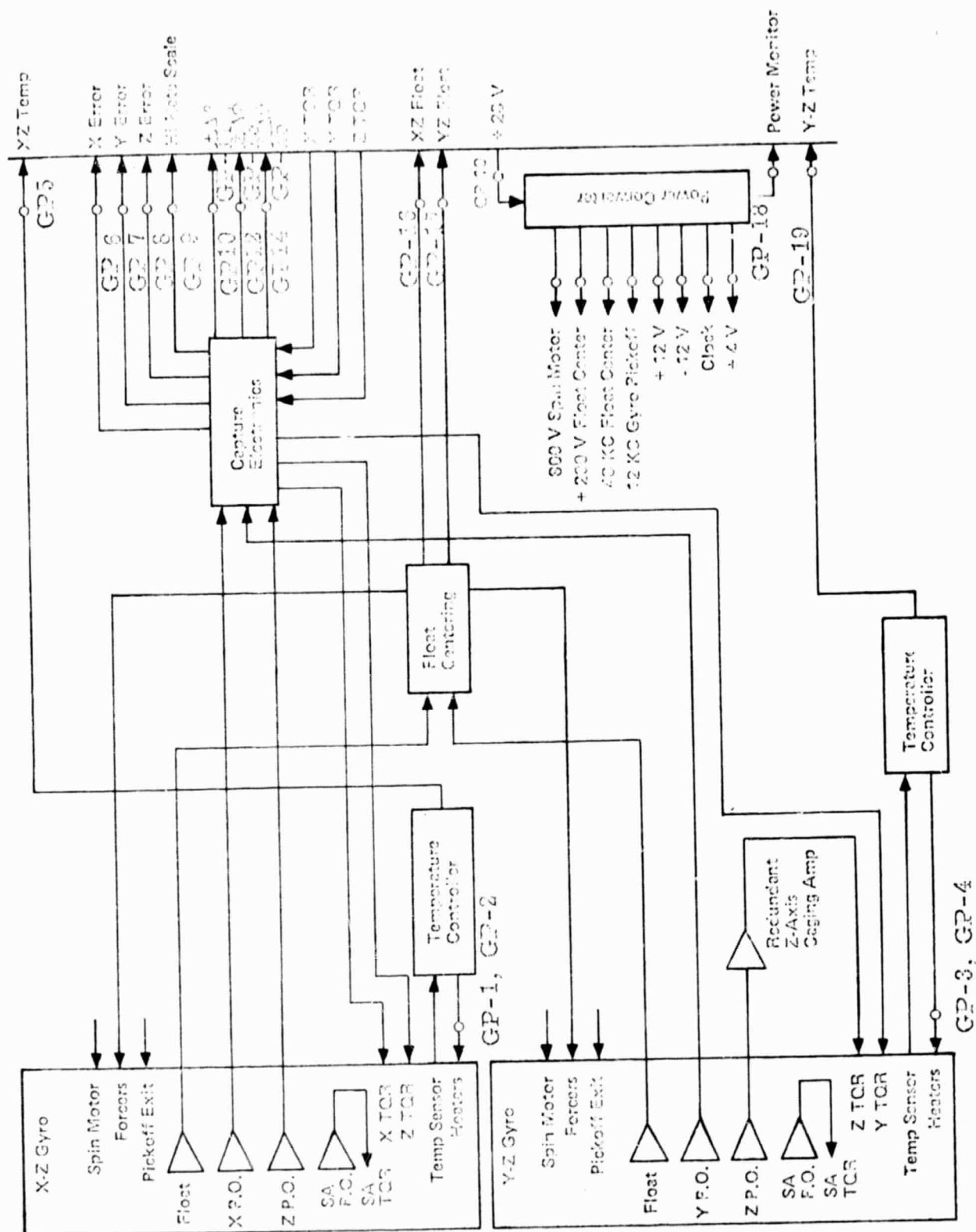


Figure 3-41. Gyro Package Onboard Test Points

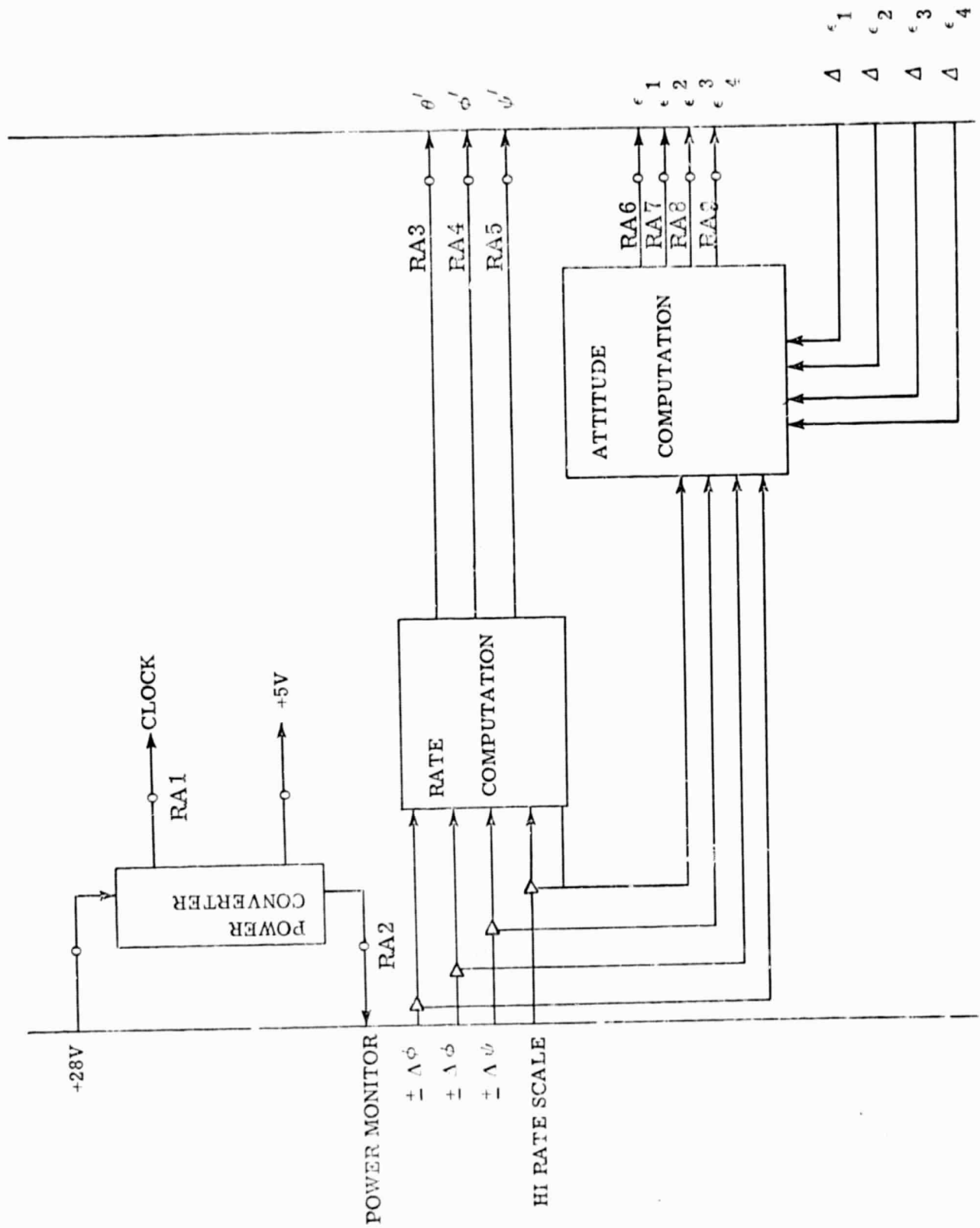


Figure 3-42. Rate/Attitude Computer Onboard Test Points

Table 3-34. Test Measurements Required for Checkout of One Gyro Package
(3 Gyro Packages Required)

Point No.	Location of Point	Signal Type	Parameters of Interest
GP-1	X-Z Heater	DC Current	Level
GP-2	X-Z Heater	DC Voltage	Level
GP-3	Y-Z Heater	DC Current	Level
GP-4	Y-Z Heater	DC Voltage	Level
GP-5	X-Z Temperature	DC Voltage	Level
GP-6	X Error	Analog Voltage	Level
GP-7	Y Error	Analog Voltage	Level
GP-8	Y Error	Analog Voltage	Level
GP-9	Hi Rate Scale	Discrete	
GP-10*	+ $\Delta \theta$	Pulse Train	Peak and Average Voltage
GP-11*	- $\Delta \theta$	Pulse Train	Peak and Average Voltage
GP-12*	+ $\Delta \phi$	Pulse Train	Peak and Average Voltage
GP-13*	- $\Delta \phi$	Pulse Train	Peak and Average Voltage
GP-14*	+ $\Delta \psi$	Pulse Train	Peak and Average Voltage
GP-15*	- $\Delta \psi$	Pulse Train	Peak and Average Voltage

*End-to-end test points.

Table 3-34. Test Measurements Required for Checkout of One Gyro Package (Cont.)
(3 Gyro Packages Required)

Point No.	Location of Point	Signal Type	Parameters of Interest
GP-16	XZ Float Control	Analog Voltage	Level
GP-17	YZ Float Control	Analog Voltage	Level
GP-18	Power Converter Monitor	Discrete	
GP-19	YZ Temperature	DC Voltage	Level

Table 3-35. Test Measurements Required for Checkout of One Rate/Attitude Computer
(3 Computers Required)

Point No.	Location of Point	Signal Type	Parameters of Interest
RA-1	Clock	Pulse Train	Peak and RMS Voltage & Freq.
RA-2	Power Monitor	Discrete	
RA-3*	ω_1	17 Bit Word	Value
RA-4*	ω_2	17 Bit Word	Value
RA-5*	ω_3	17 Bit Word	Value
RA-6*	ϵ_1	17 Bit Word	Value
RA-7*	ϵ_2	17 Bit Word	Value
RA-8*	ϵ_3	17 Bit Word	Value
RA-9*	ϵ_4	17 Bit Word	Value

*End-to-end test points.

3.4.3.4 Computer Speed to Perform Onboard Checkout

To progress from the previously developed test measurement number for a representative Space Station subsystem to a determination of computer speed requirements, the following methodology was utilized. Subsequently, this approach is applied to the Guidance, Navigation and Control Subsystem deriving the applicable computer characteristics.

Computer speed required to perform the function of onboard checkout is determined by the organization and implementation of the onboard checkout function.

Operational flow for onboard checkout (Figure 3-43) shows the implementation of test point monitoring, trend analysis, and diagnostics. Each implementation is based upon a logical structure of a test loop and its associated loop control logic, with the loop executing repeatedly until all points have been tested (or each data set has been analyzed for a trend or each replaceable unit tested for proper function). In this implementation the speed requirements are dominated by the number of instructions in the loop and the number of times it is executed. The number of equivalent adds for each of test point monitoring, trend analysis, and error diagnosis are:

Test point monitoring	100 + 10 (number of points monitored)
Trend analysis	100 + 200 (number of data sets analyzed)
Diagnosis	500 (number of assemblies)
Executive	500

To determine the computer speed necessary to perform these operations, it is necessary to bound the time allowed to successfully complete the onboard checkout functions.

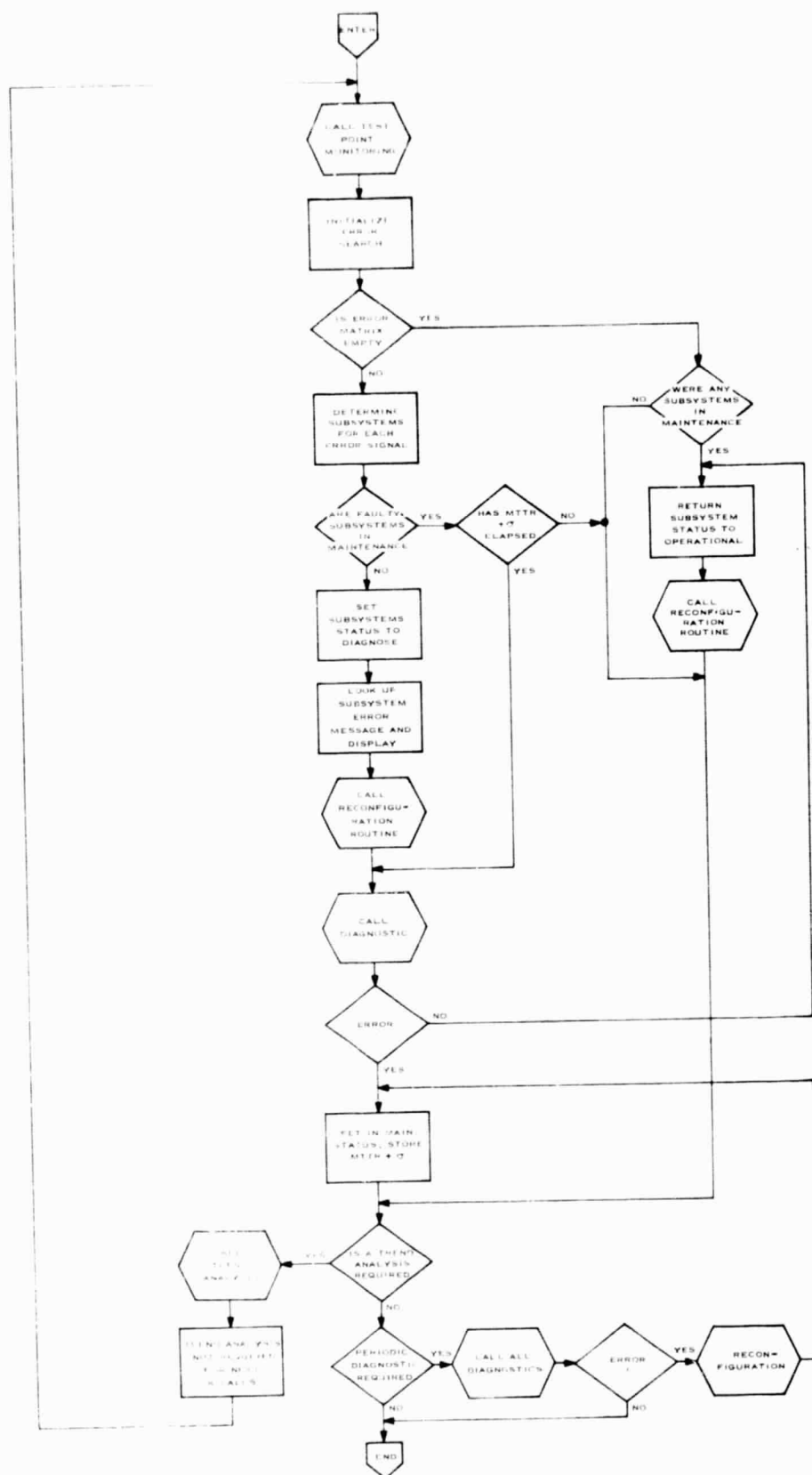
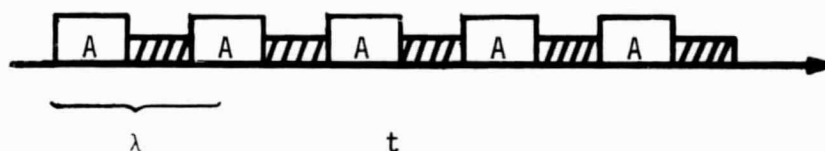


Figure 3-43. Checkout Operational Flow

One consideration bounding the time interval is the frequency at which test point monitoring, trend analysis, and diagnostics are executed. The problem here is illustrated in the diagram below:



Suppose routine A is executed every λ time units and requires some fraction of λ , as illustrated to successfully execute. Suppose also that a routine B is executed every 5λ time units. Then B can only be executed when A is not, that is, in the time periods indicated by the shaded areas. So the operations required to execute A plus $1/5$ the operations required to execute B must be executed in λ time unit. The speed required to execute A and B is $(\text{op'ts (A)} + \text{op'ts (B)})/\lambda$ op'ts/time unit. Although developed for two routines, this argument applies to any number of routines executed periodically at the same or different rates. This speed requirement which must be met is the "average" operations/time unit.

Another consideration comes from the fact that, although one program may be executed much more infrequently than another, when it is executed, it must follow the faster cycled program and be finished before the next scheduled initiation of the more frequently occurring program. For example, the monitoring routine updates the trend analysis data base every n^{th} monitoring cycle, where n is a function of the bandwidth of the signal to be analyzed for a trend, and the trend analysis routine must execute between updates of its data bank. If A is the test point monitor program and B is the trend analysis program, then required speed = $\text{op'ts (a)} + \text{op'ts (B)}/n$ in operations per cycle of A.

Finally, periodically executed routines may have long paths which are followed infrequently. For example, the checkout executive shown in Figure 3-43 is called at the test point monitor frequency but every so many calls executes trend analysis and diagnostics before exiting to the onboard computer executive. Thus, the longest path through the routine must be used to determine the maximum operations count, even though the average may be much less. This speed requirements is frequently the highest and will result in a computer, which on the average, has much idle time for other uses.

For the checkout program discussed previously, the three speeds were calculated by assuming that of 5000 total test points, 10 percent were monitored once per second to determine assembly level go-no go, while the other 90 percent were diagnostic test points; that 100 of these were subjected to trend analysis every 100 seconds, with data updated every 10 seconds (10 samples), and that once per hour all 80 assembly level diagnostics were executed to monitor replaceable unit performance. Under these assumptions the following speed requirements were derived:

$$\text{Average} \quad \frac{100 + 10(500)}{1} + \frac{100 + 200(100)}{100} + \frac{500(80)}{3600} = 5,312 \text{ op'ts/sec.}$$

$$\text{Sample Interval} = 5,100 + \frac{100 + 200(100)}{10} = 7,100 \text{ op'ts/sec.}$$

$$\text{Max} = 5,100 + 20,100 + 40,000 = 65,200 \text{ op'ts/sec.}$$

Operation = equivalent-add

To satisfy the maximum requirements, a machine speed of at least 65.2 kilo-op'ts/sec will be required for checkout, with about 60 K op'ts/sec available on the average for other activities.

Furthermore, if test point monitoring were done on an interrupt basis allowing the computational functions to be interlaced, the maximum speed would then be:

$$\frac{51,000 + 20,000 + 40,000}{10} = 11.1 \text{ K op'ts/sec}$$

or a reduction of about 50 K op'ts/sec from the maximum. Depending on the overall onboard computer program requirements, the interrupt implementation may be decided upon.

This demonstrates that computer speed requirements for subsystem computational support should, for purposes of preliminary machine sizing estimates, be characterized by both an average and maximum value of equivalent-add operation per second. Average single subsystem speed requirements may be added for determination of a composite average load; and the greatest maximum will identify the compute speed performance requirements (as the system design and a proper task scheduling policy evolve, the average computer loading will tend toward the greatest maximum value). Of course, the parameter of equivalent-add operations per seconds is only one indicator of computer speed. Dependent upon the application, specific requirements may also exist for specialized operations such as fast multiply, special trigonometric functions, etc. Nevertheless, equivalent add time is believed to be the best single indicator.

The preceding development of the functional and quantitative computer requirements in support of the onboard checkout subsystem (OCS) presumed a passive form of operation (no stimuli generation required) and centralized implementation. That is, all data was assumed to be monitored and processed by a general purpose computer as opposed to configurations featuring remote data acquisition and checkout units, or built-in test equipment (BITE). This is consistent with the objective of identifying an upper bound on computer support requirements, yet may well become unrealistic in the evolution of an onboard checkout policy, subsystem design and system organization. Nevertheless, the basic parametric relationships developed should remain valid for assessing the magnitude of that portion of the total task assigned to the OCS computer(s). This methodology is now applied to the onboard navigation and control subsystem.

3.4.3.5 Navigation and Control Subsystem

To assess the computer requirements for performing the onboard navigation and control functions, a configuration was selected (Figure 3-45), a software functional flow was hypothesized, and an evaluation was made of the required instruction count and storage. The following assumptions were made concerning the system operations and implementation:

- o A local vertical orientation for the longitudinal vehicle axis was chosen requiring a pointing accuracy of 0.01 degree. This mode (as opposed to inertial hold, solar pointing, X-POP, etc.) was chosen as it will impose the most severe computational requirements upon the digital computer.
- o Body to inertial reference obtained through strapdown inertial platform (via DDA). Inputs to the computer are in the form of direction cosines and will be read at 0.1 second intervals. Two star trackers are assumed available for periodic direction cosine updates²³. Based on the given accuracy requirement and a projected gyro drift value of 0.03 deg/hr, this update would occur approximately every 20 minutes.
- o Onboard navigation is accomplished by extrapolation of a ground supplied initial state via a Taylor series expansion of the coordinates of a body of Keplerian motion (commonly referred to as the 'f' and 'g' series). ²⁴Up to 10th order terms were required to provide the desired accuracy over one-third of an orbit.

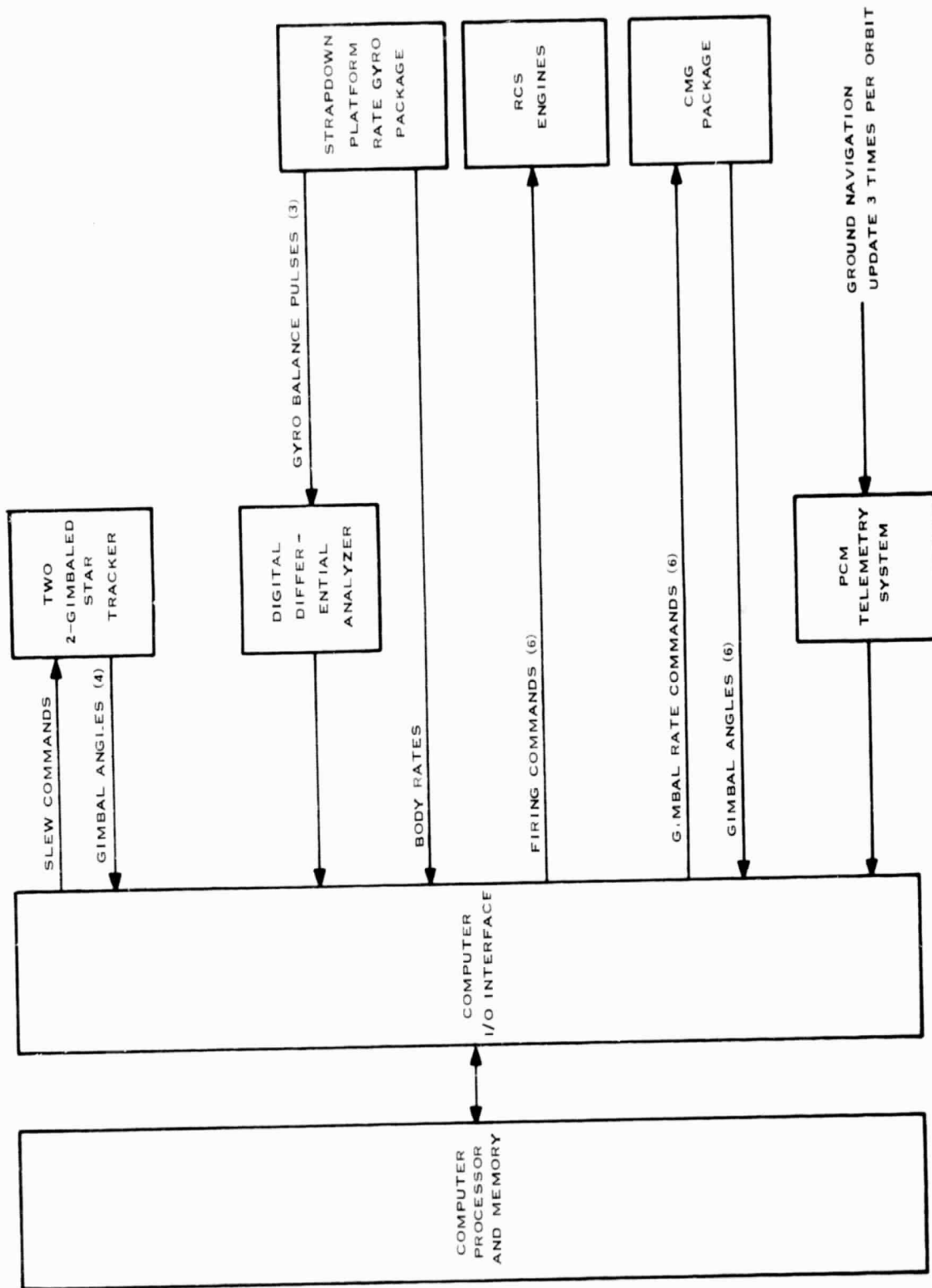


Figure 3-45. Navigation and Control System Block Diagram

- o Prime control torque is provided from three double gimballed, orthogonally mounted control moment gyros (CMG's). The H-vector control law²⁵ is utilized in conjunction with the "isogonal distribution and rotation (D&R) laws"²⁶ to generate the gimbal rate commands. No resolver chains were assumed to be on the CMG's.
- o CMG desaturation capability will be provided in two ways. One method employs rectified components of the gravity gradient torques encountered over the period of one-half an orbit to nullify the saturation effects of non-cyclic disturbance torques²⁷. The other method, which would be used only if for some reason it is undesirable to make the attitude maneuvers required of the gravity gradient technique or if the attitude momentum envelope has been breached, employs the use of the reaction control subsystem (RCS).
- o Additionally, the RCS will be available as the back-up method of control on the event of a CMG system failure. The RCS will have no pseudo rate modulation characteristics, a minimum burn-time of at least the sample period of the digital controller, and operate on a burn-time prediction scheme.²⁸

A digital program organization was developed to allow either of the two modes of attitude control. The navigation function is assumed common to both modes and the performance of that function is not affected by the control method employed. However, when using CMG control there is a requirement to process portions of the H-vector control law at a higher rate than is required for the other Navigation and Control functions. Therefore, to make efficient use of the processor time, the program is organized into two loops--primary and secondary. The primary loop is entered every 0.1 second and provides for direction cosines updating, navigation updates, attitude errors determination, desaturation commands, D&R commands

and control momentum commands. This loop also contains logic to switch out certain of the above control related activities in lieu of performing RCS computations. The secondary loop is used only in the CMG control mode and is controlled by a priority interrupt. It is responsible for generation of the CMG gimbal rate commands. An iteration rate of 30 seconds is considered in this example. The flow charts for the primary and secondary loops are shown in Figures 3-46 and 3-47. Included in the flow charts are memory storage and worst-case (longest path through the logic) machine operation requirements for each major division of the program. These numbers were based on the following assumptions concerning the processor:

- o Machine architecture similar to System 4-Pi, Model EP.
- o Elementary functions (sine, cosine, square root, etc.) encoded and wired into a Read-Only Store (ROS) control memory.
- o Operation and memory count numbers include a 30 percent allowance for indexing functions.

Based on the indicated counts the worst-case computer requirements for both loops may be summarized as:

<u>Loop</u>	<u>Memory</u>	<u>Equivalent-Add Operations</u>
Primary	2,675 Words	1,966
Secondary	205 Words	521

As CMG control requires more operations in the primary loop than RCS control, the CMG requirements are used in the worst-case figures. However, RCS memory requirements are included in the total of 2.88K words.

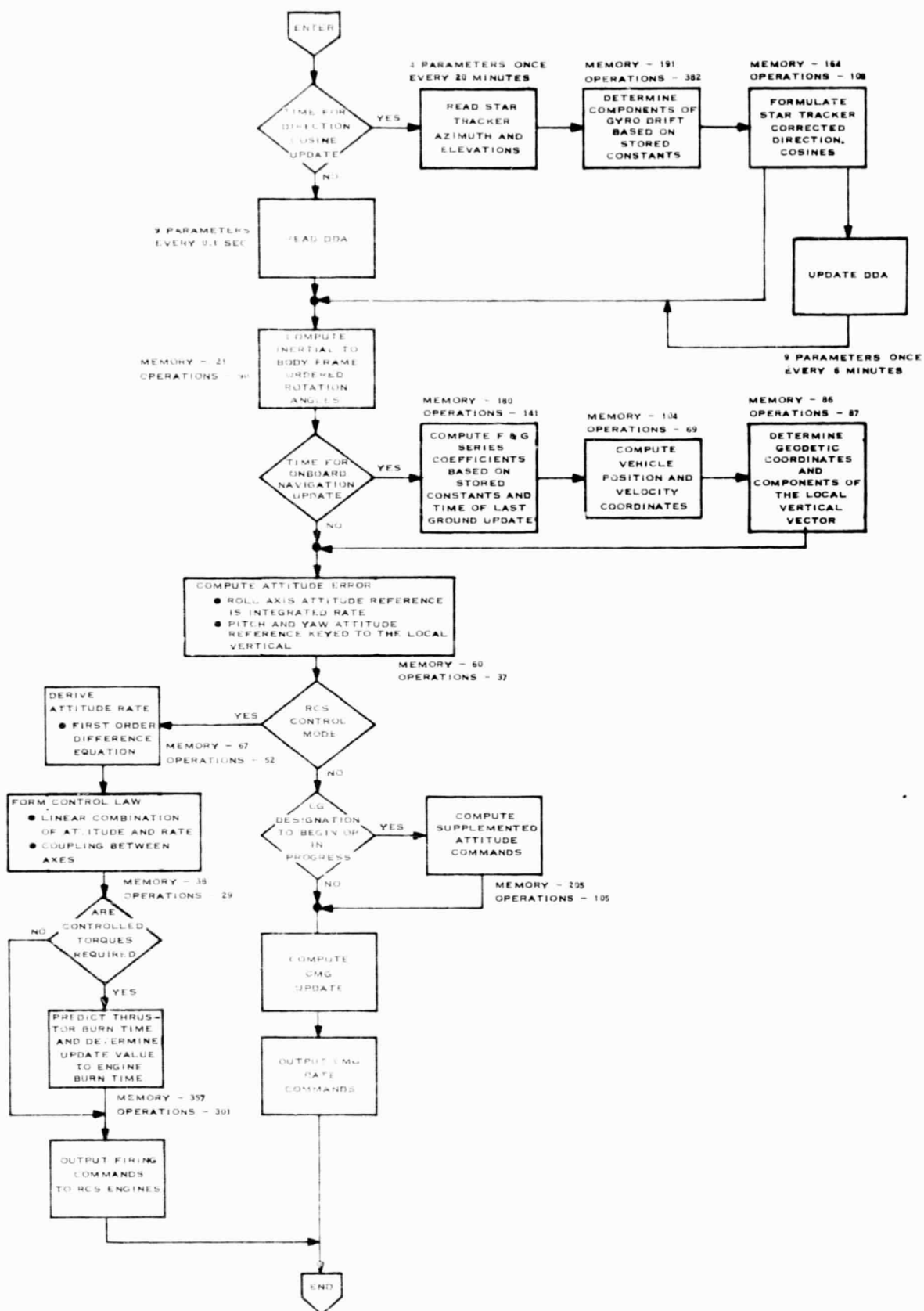


Figure 3-46. Navigation and Control Primary Loop

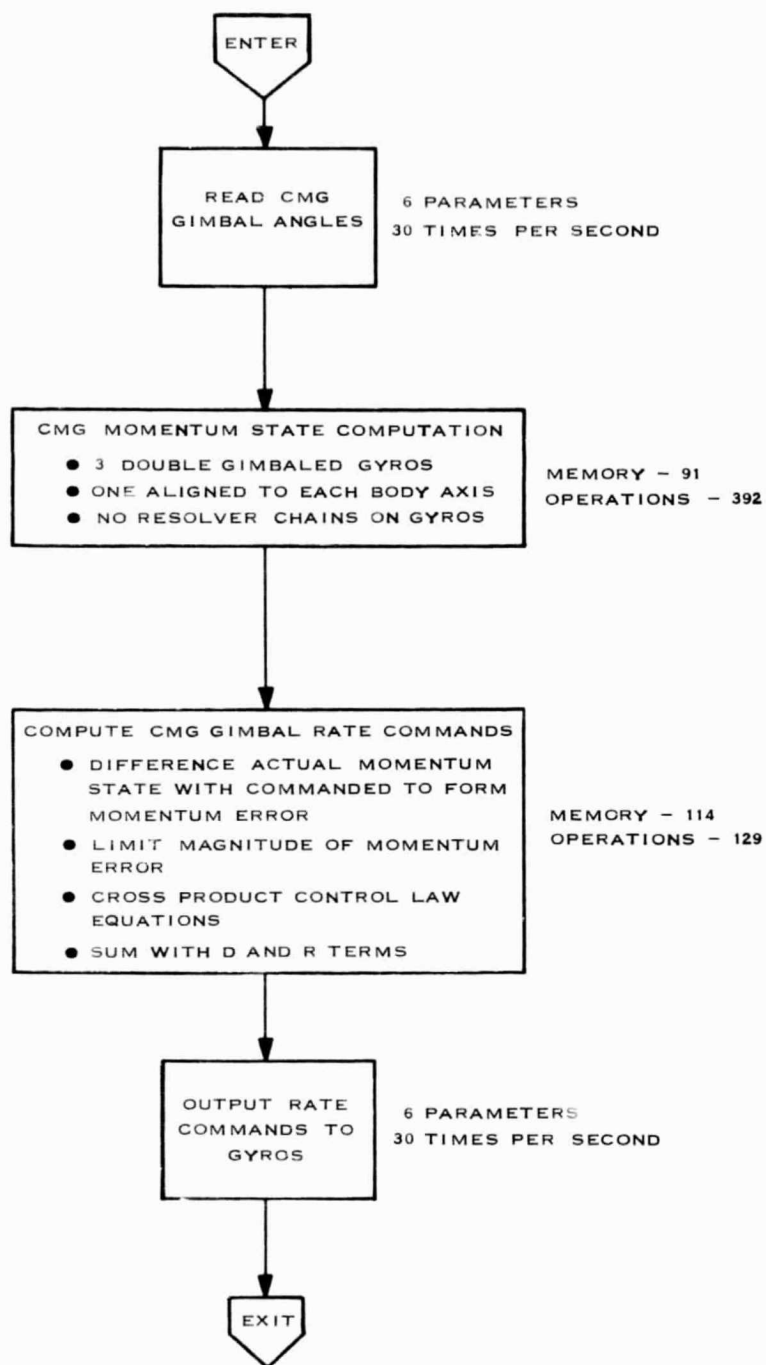


Figure 3-47. Navigation and Control Secondary Loop

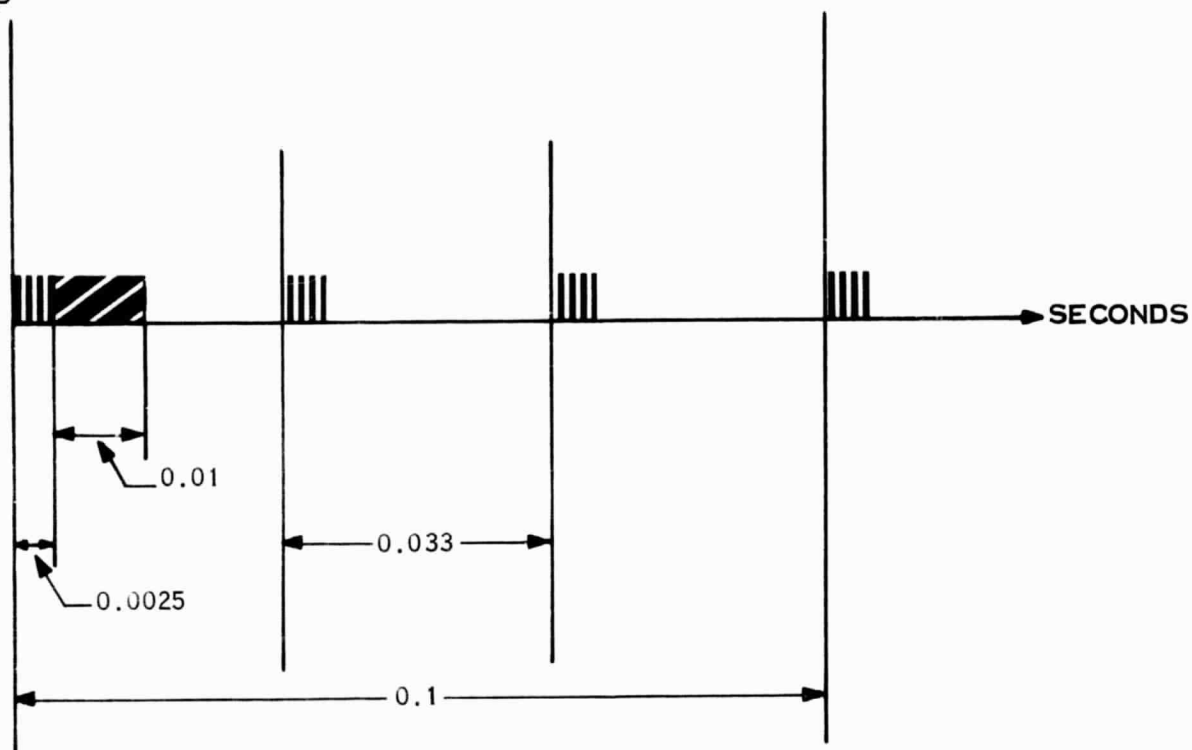
Considering the computation rates mentioned earlier and a software operational timeline as shown in Figure 3-48, the following computational speed requirements results:

<u>LOOP</u>	<u>SPEED</u>
Primary	196K Operation/Second
Secondary	208K Operation/Second

The Navigation and Control subsystem computational requirements, on a worst-case assessment basis, are therefore established to be:

- o 3K words of memory
- o 200 K (equivalent add) operations/seconds - maximum
- o 35K operations/second - average.

INITIATE
SECONDARY
LOOP



 PRIMARY LOOP
 SECONDARY LOOP

Figure 3-48. Assumed Computational Timeline

3.4.3.6 Experiment Command, Control and Data Processing

A prime task of the onboard computer system is the management and operation of experiment modules. Since experiments will be replaced by new ones as the Space Station progresses and since additional experiments will be added as the Space Station grows, the experiment data handling system must be expandable and flexible with allowance for easy modification as the experiment processing needs change. The primary functions of an onboard experiment data handling system include:

- o Experiment scheduling
- o Experiment command and control
- o Experiment data collection
- o Data storage
- o Data processing and compactification
- o Selected display of acquired data.

The successful accomplishment of these functions demand a close interaction between experimenters and operating system designers. Each experimenter must furnish data and programs with his hardware in a format which allows interface with the onboard computer operating system.

Each experiment will have its own software module, with a standard interface to the program executive which will contain the instructions necessary to perform any required calibration, initiate the experiment, sequence the experiment, and monitor certain performance test points. When the experiment is initiated any data formatting a reduction will be executed by the experimenter furnished software. To minimize storage requirements for data reduction, a standard set of data processing routines, plotting routines, and calibration and scaling routines will be furnished as part of the operating system. Experimenters will be furnished with the calling sequence and linkage requirements for each utility routine and

will be required to utilize these resident routines whenever possible. The data utility routines presently planned for the onboard computer program are found in Table 3-36. The experiment interface with the onboard computer system, experiment attitude and operational constraints, experiment duration, I/O and processing requirements, astronaut participation, power consumption, film required, bulk storage required, and other pertinent data will be required so that experiment scheduling, command, control, and execution requirements may be established.

To ensure maximum flexibility, a standard connector is assumed which has all necessary connections for discrete, serial, parallel, video, power, voice, and checkout test points. This connector is to be used by all experimenters in the design of their experiment hardware. Channel assignments and pin assignments within an I/O group will be furnished to the onboard computer as part of the initialization data to allow proper I/O address constants to be generated. The experimenter furnished software will be structured so that device addresses may be obtained by referring to a supplied table. After channel and pin assignments are determined, the experiment executive will fill the device address table with the proper address constants so that proper reference to the experiment can be accomplished during start-up and operation.

3.4.3.7 Experiment Scheduling

Periodically, the onboard computer system will execute a program which schedules Space Station activities. The largest part of this activity will be experiment scheduling which will involve:

Table 3-36. Experiment Data Handling Utility Routines*

Name	Function	Storage (Words)
Tally	Totals, means, standard deviations, minimums, maximums	248
Bound	Selection of observations within bounds	168
Momen	First four statistical moments	318
Auto	Auto covariance of a time series	148
Cross	Cross covariances	177
Chisq	χ^2 test	353
Randu	Uniform random number generator	78
MINV	Matrix inversion	466
MADD	Matrix add	72
MSUB	Matrix subtract	72
MPRD	Matrix product	163
MTRA	Matrix transpose	90
Forit	Fourier analysis of a tabulated function	237
HARM	Complex three dimensional analysis	1500
Total		4090

*Estimates derived from Scientific Subroutine Library

- o Resource requirements
 - I/O and processing
 - Bulk storage and film
 - Displays and astronaut participation
 - Power
- o Operational constraints
 - Orbital
 - Attitude
 - Sequencing
- o Time constraints
 - Duration
 - Warmup
 - Checkout
 - Calibration
- o Priority.

Hence, a large data bank will be required for experiment scheduling. An estimate of the storage requirement per experiment is found in Table 3-37. The program doing the scheduling is modified linear programming algorithm and requires approximately 2000 instructions. Hence, experiment scheduling requires $2000 + 30n_e$ location, where n_e = number of experiments.

Experiment scheduling will be done at most once per day on the average. The program should require 100-500 operations to execute, and 10 minutes is not unreasonable to complete the scheduling. Hence, at most, 1 K op/sec (avg) should suffice for scheduling. The output of the experiment scheduler

Table 3-37. Experiment Scheduling Data Base

Data Quantity		Storage
I/O:	Video (Channel)	1
	Serial (Channel)	1
	Discrete (Number in and out)	2
Processing:	Max (K ops/sec)	1
	Ave (K ops/sec)	1
Power:	Peak (Watts)	1
	Average (Watts)	1
Bulk Storage (Words):		1
Display (% of available time):		1
Astronaut Participation:	Number	1
	Minutes	1
Film:	Types	3
	Amount (Rolls)	3
Orbital Constraints (Day, Night):		1
Attitude:	Accuracy sec	1
	Actual Attitude	3
	Type Control	2
Duration (Minutes):		1
Warmup (Minutes):		1
Checkout (Minutes):		1
Calibration (Minutes):		1
Priority:		1
Total		30

will be a daily timeline with defined actions and resource allocations. This timeline will be used by the experiment executive controller to activate and run experiments.

In accordance with the timeline for action initiation and the resource allocation by the experiment scheduler, the experiment executive allocates resources by entering the proper addresses in the I/O device address tables, issues messages to the astronauts, switches in power, and requests file and magnetic tape cartridge loadings. At the proper time the experiment's power-up, checkout, calibrate software module is called. When a go is received, the experiment's operating software is called. After the completion of the experiment and all data is processed as required, the experiment is disconnected. The experiment executive is therefore a logic routine with many subprogram calls. Programs storage requirements are found in Table 3-38.

The total experiment storage requirements is found in Table 3-39. An approximate estimate is that the experiment processing average speed requirement is 100K ops/sec. Review of the experiment types ²⁹ and typical processing requirements resulted in average estimates of 5000 instructions and 2000 words of working storage per experiment and 10^5 words of digital bulk storage per experiment. It was also estimated that no more than half of the experiments would be operating simultaneously at any time. The rest of the experiments would be dormant, and their software could reside in bulk storage. Therefore, storage requirements for experiment software have been given in terms of both main and bulk storage.

Table 3-38. Experiment Executive Storage Requirements

Function	Storage (Words)
Timeline Table	$20 n_e$
Experiment Software Linkages	$80 n_e$
Executive Logic	$2000 + 20 n_e$
Call to Scheduler	40
Initialization Call	40
Total	$2080 + 120 n_e$

Table 3-39. Total Experiment Program Storage Requirements

Function	Storage (Words)
Executive	$2080 + 120 n_e$
Scheduler	$2000 + 30 n_e$
Initialization	4000
Experiment Software	$70K n_e + 100K$ (Bulk)
Total	$8000 + 7150 \frac{n_e}{2}$ (Main) $+ 1.07 \times 10^5 n_e$ (Bulk)

3.4.3.8 Inventory Management and Maintenance Procedures

Inventory management is a function which may seem simple at first thought, but for which interactions are many and the implications rather far-reaching. Certain requirements are apparent such as the need for a data bank describing the state of the inventory. It would also be desirable to have trends in item demands analyzed, unexpected usage rates identified, and realistic inventory policies implemented to track the numbers in stock and properly account for all new orders.

Another implication of inventory management is man-machine interaction. When an item is entered or withdrawn from inventory, this occurrence must be entered in the data bank. Some indications, such as from level sensors in RCS propellant tanks, will be likely ~~be~~ furnished directly to the inventory management routine. Most inventory transactions will rely on an astronaut entering, by keyboard or mark-sense card, a record of his action. Opportunities for errors are numerous, and undetected errors could have unpleasant consequences ranging from being out of salt (when the inventory management thought "n" pounds were in stock) to having a nonrepairable computer because the last spare logic card was used and unrecorded. Therefore, operational procedures must be such that it is easy to update the inventory and appropriate reminders issued if an inventory update was expected and none was received. Also, presumption of withdrawal shall be made, in the case of the spare part, when the faulty assembly is returned to operational status, if no withdrawal entry is entered.

All consumables will be included within inventory management including, life support consumables, power subsystem consumables, RCS consumables, spares, photographic film, and data recording packets.

The data stored in inventory records will consist of the items listed in Table 3-40. It is obvious that a large storage base is required. The storage requirement for a single item is 95 words/item. Table 3-41 gives the sizing estimates for this function. Certain assumptions and observations about the inventory management program are required to completely understand program operation and the resulting implications. It is assumed that the least amount of reliance is placed upon voluntary human actions, that is, sensors are provided which record human actions affecting inventory management. If greater reliance is placed on unconfirmed voluntary human actions, then the logic flow can be simplified.

There are three paths through the inventory management routing. The path taken depends on whether a shipment is being processed, a withdrawal of a consumable is being processed, or a general query is being processed. When a shipment arrives, all logic is exercised, so that an explanation for this mode encompasses all modes. The key assumptions are the existence of sensors which allow monitoring of the state of the inventory, use of inventory data to sense potential error conditions through the observation of the rate of consumption, and comparison with a predicted rate of consumption, and automatic order preparation. Sensors allow comparison of actual shipments against telemetered bills of lading, sensing of withdrawals and comparison with scheduled withdrawals, and hence, quick error detection. Inventory data is useful for determining slow leaks in tanks, low grade shorts in wiring, and similar long term error conditions. Automatic order preparation relieves astronauts of mundane chores and is consistent with the inventory data bank.

The processor speed requirement can be determined by requiring the "longest path" to be completed in five minutes. (Longer completion periods would be allowable, but unlikely.) Estimating the loop processing (of all items in the

Table 3-40. Inventory Data Base Storage Requirements, Item

Quantity	Storage (Words)
Number currently on hand	1
Number actually used and predicted usage	2
Inventory level indicating an order	1
Number to be ordered	1
Part number	1
Storage bin address	1
Number currently on order	1
Estimated order arrival date	1
Minimum lead time	1
Location receiving order	1
Standard order message	40
Message indicating inventory depletion and its significance	40
Error branch table	3
Category of item	1
Total	95/Item

Table 3-41. Inventory Management Storage Requirements

Function	Storage
Linkage	40
Mode Test	20
Input	100
New Item Test	100
Transfer of data to Data Bank	40
Supply Check	100
Time Check	10
Astronaut Communications	300
New Delay Time	10
Data Bank Update	150
Items leaving Test	100
Data Bank Update	150
Supplies withdrawn processing	100
Trend Analysis	200
Error Messages	$40n_I$
Order preparation	150
Inventory Status Printout	300
Order transmission	300
Exit Linkage	40
Data Bank	$94n_I$
Total	$2210 + 134n_I$

inventory) yields $200 + 600 n_I$ operations, for worst case. If there were 3000 items in the inventory ($n_I = 3000$), then $1.8 \times 10^6 / 300 = 6 \times 10^3$ ops/sec (average) would be required for inventory management. The storage requirement corresponding to 3000 items is 404,000 words.

The storage of spare parts in the Space Station, with repair upon failure for all Space Station subsystems planned, implies the existence of a maintenance procedure for each replaceable unit with the Space Station. If these are stored as hard copy, they do not impact computer system requirements except as items in inventory management. However, if these procedures reside within the computer system and are furnished as required, a large amount of bulk storage would be required to store these procedures. In addition, they would probably be indexed by part number so a branch table correlating part number and address in bulk storage for the procedure would be required in main storage. If an average procedure was 4 pages of 66 lines of 132 characters in length, 8712 words of bulk storage would be required for each procedure. If there were 1200 replaceable units, then 10,454,400 words of bulk storage would be required for the maintenance procedures and 2400 words of main storage for the address table.

3.4.3.9 Other Requirements

There are functional requirements in addition to those previously discussed which may either demand or beneficially utilize computer support. For other than the coast phase of the Space Station mission, guidance functions will potentially require significant computer support. However, they will likely be implemented in a launch vehicle astrionics system for ascent and certainly

in the re-entry vehicle for atmospheric re-entry and descent. Of course, for interplanetary flights such as a Mars flyby, there will be a need for some form of earth-to-Mars powered-flight guidance for trajectory correction purposes. However, this could result from ground generated commands. The onboard computer implemented guidance functions are thus considered negligible.

There are a number of functions related to telecommunications which will require computer support, including:

- o Transmission
 - viewing range calculations
 - onboard antenna selection
 - telemetry mode switching
- o Data handling
 - formatting
 - data flow control (buffer storage, addressing, etc.)
- o Tracking
 - ground track prediction.

Previous estimates for these functions were 15K words of memory and 50K³⁰ operations/second, maximum.

Numerous data management functions are anticipated such as:

- o Routing of data between various memory hierarchy levels
 - from slow access bulk storage to computer(s) working memory
 - from main memory to telecommunications systems buffer storage
- o Multiplexor unit control associated with data acquisition and a data bus system

- o Data routing and cycling for display purposes, e.g.,
hi-speed regenerative loops for flicker-free display
- o Manipulation of data from files to displays and back to
files
- o Transfer to data from film to digital form for processing/
display and back to film via film reproducers.

These type of operations will be considered to be a subset of the total electronics system executive control (the hypervisor).

Configuration control is an essential element of Space Station operations. Reconfiguration is required in conjunction with attitude reorientations, unit failures, etc. The most demanding aspect of this function stands to be the memory and message requirements associated with configuration changes. This, again, is a hypervisor function for which sizing requirements are given later.

Signal calibration becomes a significant item of mission control-- as testified by IBM-FSC personnel supporting the NASA-MSC Real Time Computer Complex. Calibration curve polynomials of $\leq$ fifth order are computer-stored for conversion of digital data into engineering units for display, etc. On the average, it has been found that 3.5 words of memory per mission control parameter are required for calibration. For autonomous Space Station/Space Base operations, as many as several thousand parameters might desirably be monitored. Therefore, approximately 8K word-memory should be allocated to this function. Computational speed requirements are, however, considered rather negligible on an average basis and nondominant on a maximum basis.

It is expected that power management functions will become largely computerized. Remedial switching, redistribution of loads, and loads priority assignments are candidates for computer control as they are partly dependent upon other computer-contained parameters. Also, load priorities will be a functions of mission phase and events and should therefore be defined by both pre-programmed and contingency logic methods, which are ideally suited to computer implementation.

The environmental control/life support subsystem will also require some computer support--yet to be determined.

The sum total of executive control functions typically constitutes 10 to 20 percent overhead.

Storage estimates have been derived for the various major functional requirements. No attempt was made, in the previous sections, to indicate the storage allocation to main storage, such as tape or disk. The recommended allocation presented in Table 3-42 shows that most of the data and all of the infrequently used programs reside in bulk storage.

3.4.3.10 Summary of Results

Based upon the total Space Station requirements derived via the analytical techniques previously presented, the computer system requirements were estimated and are presented in Table 3-43. The summary requirements are:

- o Average speed - 191K ops/sec
- o Maximum speed - 600K ops/sec
- o Main storage (32 bit words) - 378K
- o Bulk storage (32 bit words) - 7.5×10^6
increasing 4.3×10^7 with maintenance procedure storage.

The computer requirements are based upon the following assumptions:

- o Number of assemblies - 80
- o Number of replaceable units - 2000
- o Number of test points - 5,000
- o Number of experiments - 60
- o Number of items in inventory - 3000.

Table 3-42. Main and Bulk Storage Allocations

Main	Bulk
Executive Control Program	Inventory Data Bank
Inventory Management Program	Diagnostics
Navigation and Control	Experiment Programs
Checkout Executive	Trend Analysis Data Bank
Test Point Monitor	Maintenance Procedures
Trend Analysis	Experiment Scheduler
Configuration Management	Experiment Scheduler Data Bank
Experiment Control Program	
Utility Routines	
Display Control Routines	

Table 3-43. 1975-80 Computer System Requirements

Function	(Ops/Sec) Average Speed	(Ops/Sec) Maximum Speed	(32 Bit Words) Main Storage	(32 Bit Words) Digital Bulk Storage
Onboard Checkout	5K	65K	20K	58K
Navigation and Control	35K	200K	3K	---
Experiment Control and Processing	100K	500K	210K	6,000K
Inventory Management	1K	5K	5K	402K 10,000K*
Hypervisor	30K	100K	40K	---
Telecommunications	10K	50K	15K	---
Other	10K	50K	15K	---
Total Maximum + Margin (20%)	191K	500K 600K	318K 378K	6.46 x 10 ⁶ 3.65 x 10 ⁷ * 7.5 x 10 ⁶ 4.3 x 10 ⁷ *

*Maintenance Procedure Storage

3.4.4 Configuration Options - Onboard

Three candidate OCS concepts are discussed with emphasis placed on the functional arrangement of the onboard data management subsystem components, namely:

- o Data acquisition units
- o Computer including bulk storage
- o Telecommunications
- o Type and location of test equipment.

A preferred OCS concept will be selected on the basis of having the best mix of advantages for meeting the system requirements. In each of the three candidate systems the central general purpose digital computer will be a multiprocessor. A typical multiprocessor (Figure 3-49) configuration permits each processing unit to access either data or instructions from the shared memory unit. Additional communication is possible by way of the shared bulk memory, although it is not mandatory. With proper software design, each processor can work independently on the same or parallel data streams and, in the ideal case, will produce processing speeds equal to twice that of the individual arithmetic processors. The advantages of the multiprocessor are: increased speed without increasing circuit density and processing unit complexity, and increased reliability because each of the processing units can operate independently if required. Disadvantages are: increased software complexity and some degree of data sensitivity.

3.4.4.1 OCS Concepts

OCS Concept "A" (Figure 3-50) requires that each component incorporate in its design all of the necessary test equipment for performing the test function

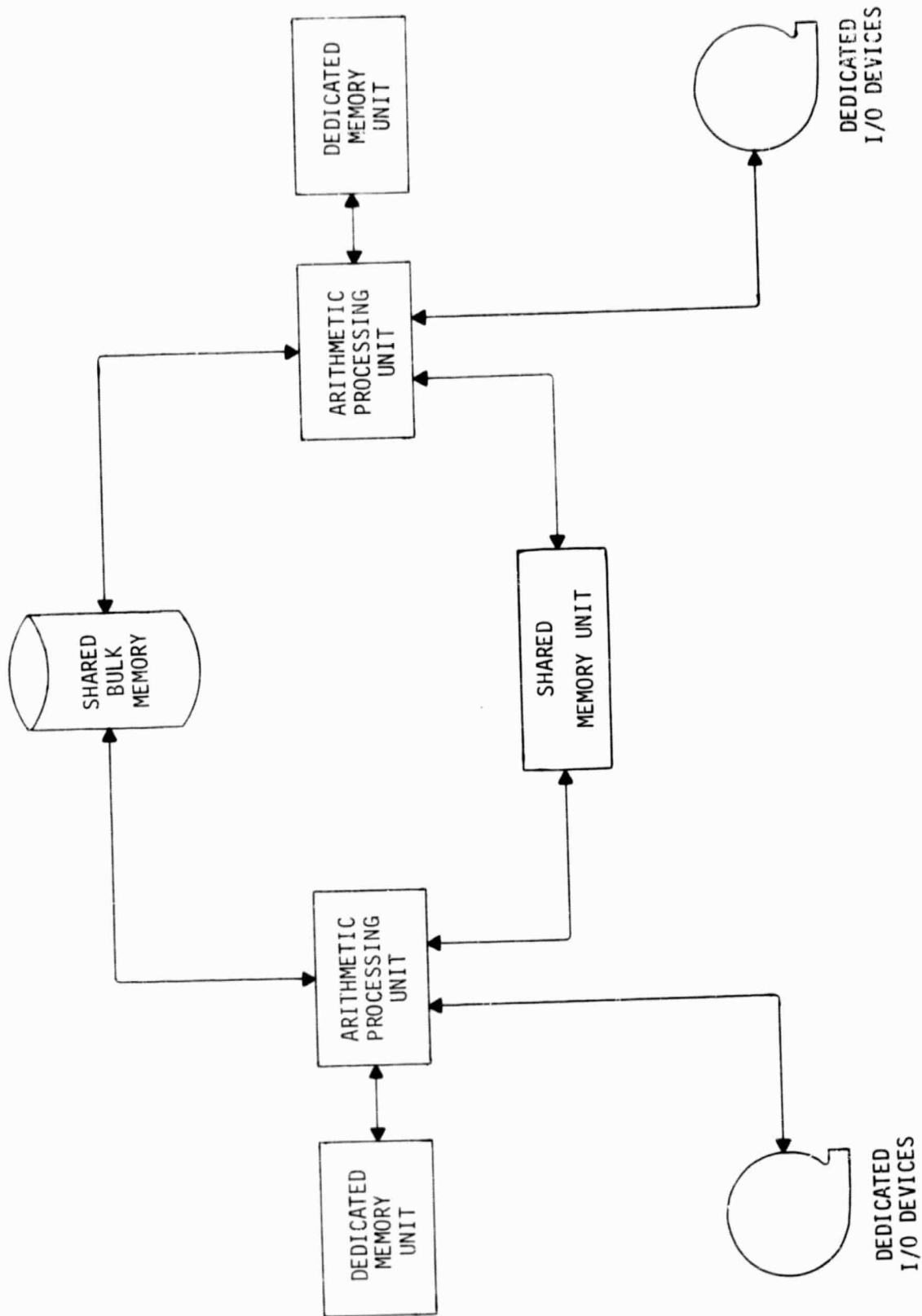


Figure 3-49. Typical Multiprocessor Configuration

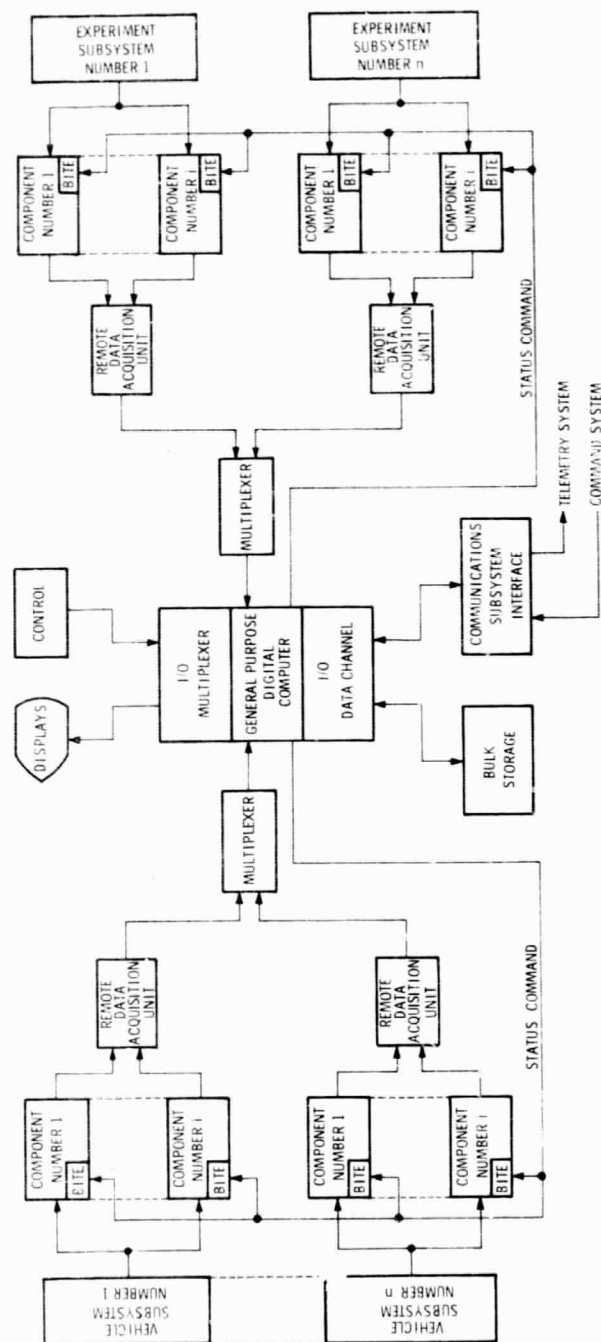


Figure 3-50. Concept A

including stimuli generators, if needed, and logic circuits for evaluation of intolerance performance. This component BITE must permit each component to assess its own operational status and report its condition to the computer upon command. The central computer performs the status interrogation function and trend analyses. The remote data acquisition unit (RAU) acts as a signal conditioner, analog to digital converter, and multiplexer.

The chief advantages of Concept A lie in investing the total testing function within the component thereby permitting adoption of a single cable concept for the onboard data network. This reduction of system interfaces does result in penalties as noted in Table 3-44. The lack of modularity within the system implies the following:

- o The computer cannot participate in self-test of the component BITE because only status data is available. Running out another wire for BITE fault isolation is contradictory to the single cable philosophy.
- o Until the entire operational software system is running, no one section of it can be considered safely checkout out.

Since there is no way of differentiating the condition of prime of test equipment from the component status signal, a BITE failure may necessitate component replacement.

Concept B (Figure 3-51) differs from A in that BITE and the RAU have been replaced by remote data acquisition and checkout units (RACU), stimuli generators and switching units. The RACU performs all of the functions of the RAU and in addition is capable of performing limit checks.

Table 3-44. Advantages and Disadvantages for OCS Concept "A"

ADVANTAGES	DISADVANTAGES
● SINGLE PROCESSOR - ONE PROGRAMMING LANGUAGE ● SINGLE SOFTWARE SYSTEM - EASE OF CONFIGURATION MANAGEMENT - EASIEST CONCEPT TO PROGRAM ● MINIMUM SPACE AND POWER REQUIREMENTS ● ADDED COMPONENT TEST EQUIPMENT SIMPLIFIES OCS REQUIREMENTS	● COMPLEX SYSTEM IN OPERATION ALL THE TIME ● SINGLE POINT OF FAILURE - BOTH MACHINE AND SOFTWARE ● BACKUP MUST DUPLICATE COMPLETE SYSTEM ● INTERCONNECTION OF ADDITIONAL COMPUTERS IS DIFFICULT ● BITE FAILURE MAY NECESSITATE COMPONENT REPLACEMENT ● BITE FAILURE MAY SHOW A BAD COMPONENT GOOD ● COMPONENT TEST EQUIPMENT INACCESSIBLE FOR CENTRAL COMPUTER ANALYSES, E.G., SELF TEST

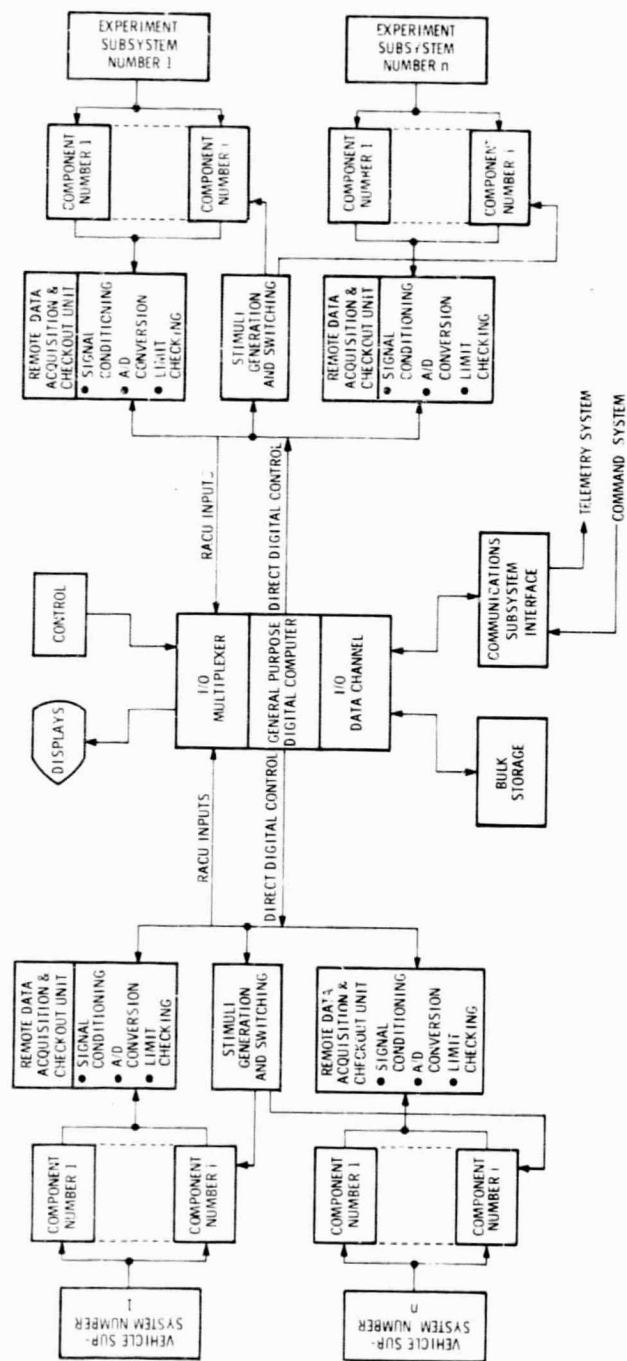


Figure 3-51. Concept B

The RACU shown in Figure 3-52 is a specialized component which performs preset limit comparison for 32 data channels. If more than 32 data points are necessary for a given subsystem, multiplexing would be used for additional RACU's. In normal operation when a limit check test routine is requested, a checkout command would be channeled to the proper cable and interrogate the specific RACU with a command address. This command address is decoded by the addressed RACU, and a checkout sequence for the tested subsystem is started. The RACU will sequence through the 32 data inputs. Each data input will be compared to high and low limits which have been stored in the RACU memory. These limits are alterable by the addressing function.

If all data values are within established tolerances, the RACU transmits an OK signal to the computer. If any data point value falls outside of the stored high/low limits, this data point is tagged with an address and returned to the computer. The checkout of the entire space station proceeds in accordance with the test routine by sending out successive RACU checkout commands addresses until all needed RACU's have been interrogated.

Based on the magnitude of out-of-tolerance conditions reported by an RACU, it may be necessary to perform a more detailed analysis on an experiment/vehicle subsystem by a diagnostic test routine. In this event an out-of-tolerance data channel address is selected (combined with the proper RACU code). When the system is in this mode, the selected data channel may be checked by the diagnostic test routine.

The major disadvantage of Concept B (Table 3-45) lies in the single-point-of-failure for the central computer and its requirement for performing all of the diagnostics and trend analyses. Eliminating BITE permitted separate maintenance for the limit checking and stimulus generator equipment. Since

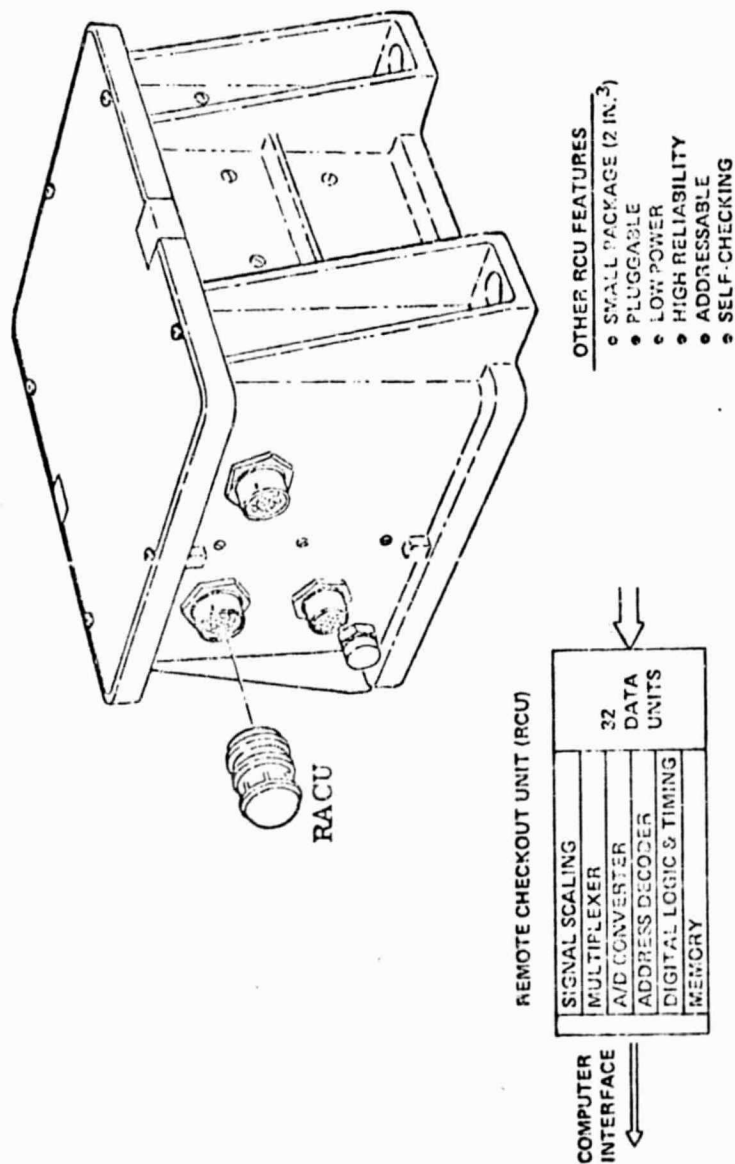


Figure 3-52. Remote Data Acquisition and Checkout Unit Application

Table 3-45. Advantages and Disadvantages of OCS Concept "B"

ADVANTAGES	DISADVANTAGES
● COMMONALITY OF STIMULI REQUIREMENTS CAN BE READILY HANDLED BY STIMULUS GENERATOR ● TEST EQUIPMENT READILY CHECKED USING BACKUP CENTRAL COMPUTER PROGRAMS ● RACU READILY MAINTAINED AND INDEPENDENTLY OF PRIME EQUIPMENT	● SINGLE POINT OF FAILURE ● DIAGNOSTICS AND TREND ANALYSIS DIFFICULT SINCE CENTRAL COMPUTER MUST HANDLE ENTIRE LOAD ● COMPLEX SPARES PROVISIONING PROBLEM FOR SEPARATE TEST EQUIPMENT

self test of the OCS is a system requirement, this added maintenance capability for the test equipment was achieved without added complexity or decreased reliability.

The preferred OCS configuration (Figure 3-53) is concept C. The RACU's are replaced by the preprocessor which performs all of the RACU functions plus subsystem diagnostic and trend analysis. Note that the RACU replacement is not on a one-for-one basis, and several RACU's can be incorporated into one preprocessor. In Concept C status monitoring, limit checking and short term trend analysis takes place in the preprocessor with display and control, data logging, and extensive mathematic analyses performed by the central computer complex. To take full advantage of Concept C's inherent redundancy, the preprocessor should have access to the onboard telemetry system (in backup mode) and some form of rudimentary display controllable from the preprocessor may be desirable.

3.4.4.2 Preferred Onboard Computer System Concept

Concept C, because of its modularity, is extremely flexible (Table 3-46). The preprocessors can be used as backup for each other, and the central computer complex can be used as a final backup. Additional functions are readily included, with proper software/hardware design. New preprocessors brought up later in the life of the Space Station can be incorporated with minimum difficulty. On the other hand, this system is the most complex of the three presented concepts (although not less reliable). More than one machine type must be programmed and maintained. The number of computation modules implies that, in terms of volume and power, requirements are highest for the same level of computational capability.

Concept C will use integrated testing, and test equipment will be located in the system to optimize the test function. While this means that BITE will

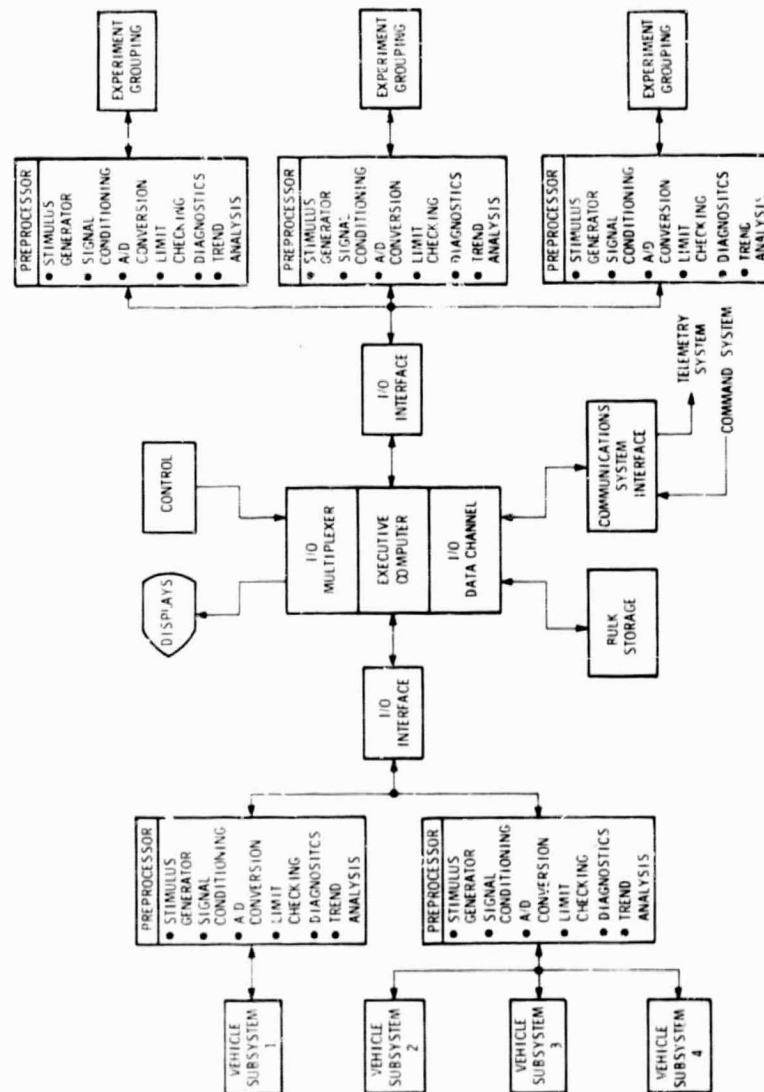


Figure 3-53. Concept C

Table 3-46. Advantages and Disadvantages of OCS Concept "C"

ADVANTAGES	DISADVANTAGES
● MODULAR PROGRAM CHECKOUT ● N-WAY BACKUP IS POSSIBLE ● FAIL-SOFT ● CHECKOUT COMPUTERS ARE PHYSICALLY INTERCHANGEABLE ● READILY LENDS TO INTEGRATED TESTING SINCE PRE-PROCESSORS WILL USUALLY BE REQUIRED FOR ROUTINE PROCESSING OF OPERATIONAL DATA	● MULTIPROCESSORS ARE DIFFICULT TO PROGRAM ● MORE THAN ONE MACHINE TYPE ● MAXIMUM SPACE AND POWER REQUIRED

not be specified for all components, this does not preclude using BITE, particularly for stimulus generation if the system analysis indicates this is desired. Figure 3-54 is an expanded version of Concept C drawn to meet the requirements of the 1975 space station core module. An attempt has been made to show all the subsystems and experiments that might be included for this mission, and the number of preprocessors used is arbitrary. More than one subsystem would be connected to a single preprocessor unless the functions of that subsystem are critical.

If the navigation system is connected directly to the top preprocessor while the water and food management systems are connected to the second preprocessor, this is the system configuration under normal operation; the switchable unit (SSU) routes the input appropriately. If a malfunction occurs, the SSU can switch the navigation and control functions to the second preprocessor while at the same time disconnecting the inputs from the first preprocessor. In addition to this functional redundancy, the executive computer can also run the preprocessor programs providing a full three-way backup capability.

Ordinarily, the executive machine is servicing displays, handling interfaces with other systems, and controlling the peripheral equipment. Since it is important to retain as much computing power as possible in the master computer, these are all the functions that would be planned for the initial application. The computer does have access to the data management subsystem so that it can serve in a support role for experiment analysis.

3.4.4.3 Computer Characteristics

The recommended Space Station central computer is a multiprocessor with characteristics shown on Table 3.47. The computer is modular and has a memory capacity of 500K to 750K words and processing speeds up to 750K

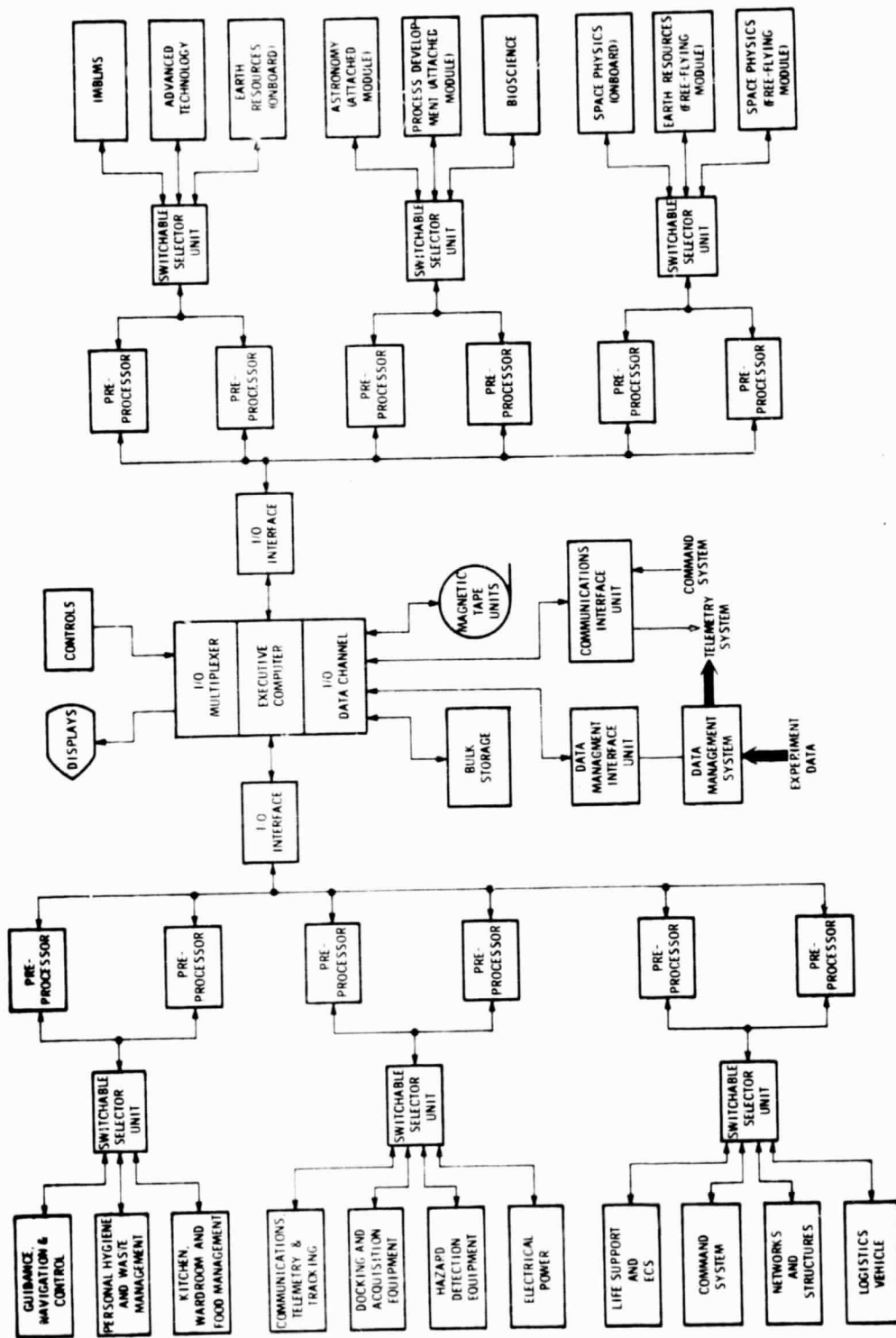


Figure 3-54. Expanded Concept C Preferred

Table 3-47. Advanced Space Station Computer Element Characteristics

CHARACTERISTIC	DESCRIPTION
TYPE	GENERAL PURPOSE, DIGITAL
ORGANIZATION	PARALLEL, MULTIPROCESSOR, FIXED AND FLOATING POINT
INSTRUCTION SET	128 INSTRUCTIONS TYPICAL OF 360/75 INSTRUCTION SET
INSTRUCTION WORD	16 or 32 BITS DOUBLE OPERAND INSTRUCTIONS NOT EXCLUDED NOR SPECIFICALLY REQUIRED AT PRESENT. DOUBLE PRECISION ARITHMETIC OPERATIONS REQUIRED.
DATA WORD	1, 8, 16, 32, or 64 BITS
ADD TIME	1.0 to 2.0 MICROSECONDS
MULTIPLY TIME	5 to 10 MICROSECONDS MAXIMUM
OPERATION/SECOND	500,000 to 750,000
MEMORY: TYPE CAPACITY	LOW POWER, HIGH DENSITY 512,000 to 1,024,000 WORDS ADDRESSABLE, RANDOM ACCESS, MODULAR IN 8K-32K WORD MODULES
CONTROL	NO REQUIREMENT WHICH PRECLUDES CONTROL STORE OPERATION

Table 3-47. Advanced Space Station Computer Element Characteristics (Cont.)

CHARACTERISTIC	DESCRIPTION
INPUT/OUTPUT: DATA CHANNELS DATA RATES INTERRUPTS DISCRETES	8-32 BIT PARALLEL CHANNELS (PCO, PCI, ECO, ECI) 50,000 - 250,000 BYTES (8 BITS) PER SECOND SIMULTANEOUSLY ON ONE INPUT AND ONE OUTPUT CHANNEL UNLIMITED EXTERNAL INTERRUPTS WITH 16 HARDWARE PRIORITY LEVELS 32 DISCRETE WORDS IN, OUT
COUNTERS	ONE 1-2 SECOND REAL-TIME COUNTER WITH 24 MICROSECOND RESOLUTION. TWO PROGRAM LOADABLE COUNTERS WITH 25 MICROSECOND RESOLUTION.
RELIABILITY	RELIABILITY GOAL OF 0.99 FOR 10,000 HOURS OF CONTINUOUS OPERATION OR 0.99 FOR TWO-YEAR MISSION OF 57 PERCENT DUTY CYCLE WHICH MAY OR MAY NOT BE EQUIVALENT
ERROR DETECTION	FUNDED STUDY (HOUR UNDERWAY) SHOULD DERIVE ADEQUATE ERROR DETECTION/MASKING STRATEGY AND HARDWARE ORGANIZATION WHICH, ALONG WITH INTERNAL MODULARITY AND REDUNDANCY, WILL ALLOW ACHIEVEMENT OF ABOVE RELIABILITY GOAL. MUST HAVE AUTOMATIC RECONFIGURATION UNDER FAILURE CONDITIONS. RECONFIGURATION TIME (Rt)=1 MILLISECOND; CONSIDER TRADES FOR INCREASING (Rt) TO 20 MILLISECONDS.
TECHNOLOGY	NO FIRM REQUIREMENTS, UTILIZATION OF MSI OR LSI FAVORED AS POSSIBLE TO MINIMIZE PHYSICAL SIZE, POWER, ETC., AND FACILITATE ERROR DETECTION. TECHNOLOGY CUTOFF FOR DESIGN AND PRODUCTION ASSUMED TO BE 1974-75.
PHYSICAL	PHYSICAL PARAMETERS AT PRESENT ARE CONSIDERED TRADEABLE FOR THE ACHIEVEMENT OF THE DESIRED RELIABILITY. GENERAL GOALS, HOWEVER, MAY BE STATED AS FOLLOWS: POWER - 300 - 500 WATTS MAXIMUM WEIGHT - 700 POUNDS MAXIMUM SIZE - 2 FT ³

operations/second. The multiprocessor will provide a structure which is readily adaptable to widely varying data loads, computational requirements expected during the different mission phases, and offers a graceful degradation feature which will enhance availability for critical functions.

The physical characteristics of the computer are:

Power - 500 watts maximum

Weight - 100 pounds maximum

Size - 2 cubic feet

The preprocessor will be a smaller version of the central computer and will have operating speeds of 200K operations/second and memory capacity of 23K 32-bit words. The physical characteristics of the preprocessor were not estimated because of the added data acquisition units and stimulus generators which were not addressed in this study. The preprocessor requirements and design should be developed in a follow-on study.

3.4.4.4 Projection to Space Base Checkout Data Management Subsystem

A Design Referenced Model for the 1975-85 Space Station/Space Base is shown (Figure 3-55) to present the system evolution concepts in their proper perspective. Note that in addition to the initial Space Station core module, several additional 33-foot diameter stages will be mated in the final configuration.

Experiment groupings will increase dramatically over the ten-year station life. Initially, most experiments will have their sensors and equipment distributed throughout the Station; but soon new modules, both attached and free flying, will be added. Eventually, a balanced grouping will result with entire sections of the Space Base devoted to research laboratories. Experiment test points

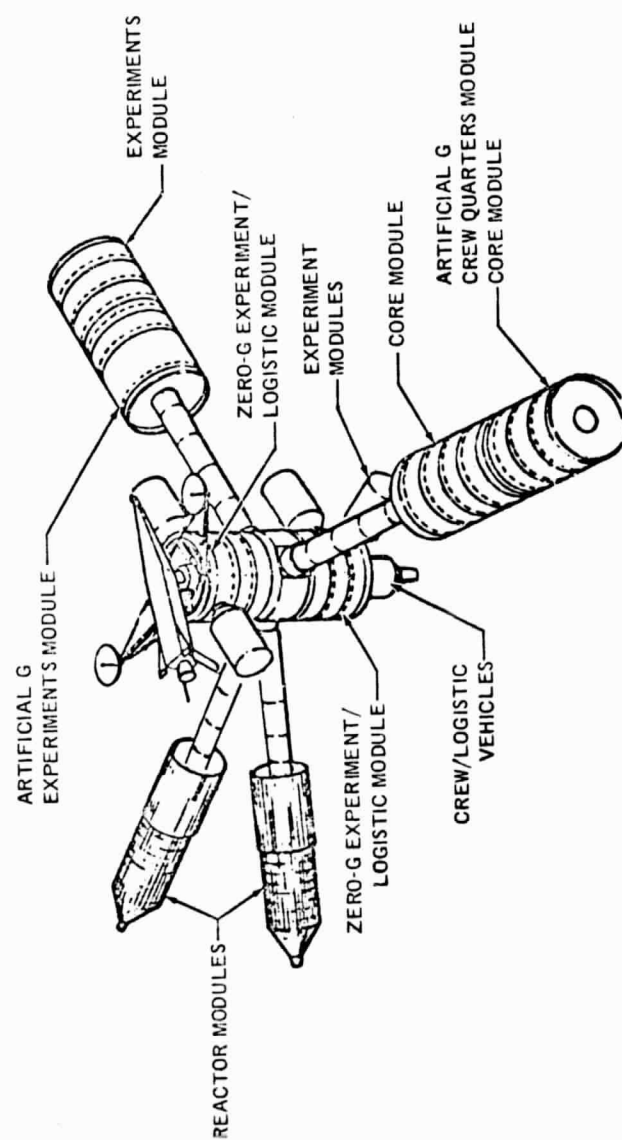


Figure 3-55. Candidate 1985 Space Base Configuration

are expected to grow from 992 in 1975 to 3,517 by 1985 (Table 3-48). Assuming requirements to not change over the decade of interest, it is easy to see that the new 33-foot diameter stages should have their own onboard checkout systems with sufficient capacity to handle the added experiments. This will ultimately result in three or more such checkout systems.

During the ten year lifetime of the Space Station, the experiment data management subsystem is expected to undergo drastic changes (Table 3-49). When the full Space Base concept has evolved, all experiment data will be analyzed onboard by scientists and principal investigators that are part of the crew. Ground computers can assist in this experiment data processing. This will be decided in each instance to obtain maximum utilization of onboard and ground processing capabilities.

Initially, all data gathered on film or by vidicons will be sent to the ground by either a television system or film return in small reentry vehicles. Eventually, however, the onboard systems must be able to process pictures and other imagery data without intermediate ground handling.

Figure 3-56 show the evolutionary test point trend for the OCS of the Space Station's core module. Initially, it will monitor 80 percent of the test points provided by the component manufacturers, but as crew confidence in the vehicle subsystems grows, the number of inflight checkout measurements will decrease somewhat.

Initially the ground flight controllers will want the capability to monitor all of the vehicle test points; but again, as confidence grows, more and more reliance will be placed in the onboard system, and most ground status monitoring

Table 3-48. Space Station Experiment Evolution from 1975-1985

1975	1985
● MINIMUM CORE GROUPINGS - IMBLMS - ASTRONOMY MODULE - EARTH RESOURCES - ADVANCED TECHNOLOGY - ENGINEERING OPERATIONS ● 1000 SYSTEM TEST POINTS ● ONLY ONE ONBOARD CHECKOUT SYSTEM AVAILABLE	● BALANCED GROUPINGS - BIOMED AND BIOSCIENCE LABORATORIES - ADVANCED TECHNOLOGY - ADVANCED ASTRONOMY MODULE - SPACE MANUFACTURING SYSTEM - SPACE PHYSICS LABORATORY - EARTH RESOURCES LABORATORY - ENGINEERING OPERATIONS ● 3500 SYSTEM TEST POINTS ● THREE OR MORE ONBOARD CHECKOUT SYSTEMS AVAILABLE

Table 3-49. Evolution of Experiment Data Management Subsystem

1975	1985
● DATA COMPRESSION AND FORMAT GENERATION ROUTINES PERFORMED BY ROS COMPUTER ● DATA TRANSMITTED TO THE GROUND CONTINUOUSLY ● MOST SCIENTIFIC ANALYSIS OF THE DATA PERFORMED ON THE GROUND ● ALL VIDEO INFORMATION RETURNED TO THE GROUND BY PHYSICAL FILM RETURN OR TV	● MOST OF THE DATA MANIPULATION PERFORMED BY AN ON-BOARD DATA PROCESSING SYSTEM ● DATA TRANSMITTED TO THE GROUND ON REQUEST OR WHEN GROUND HAS BETTER CAPABILITY FOR PROCESSING ● MOST SCIENTIFIC ANALYSIS OF THE DATA PERFORMED ON BOARD - PRINCIPAL INVESTIGATORS PART OF THE SPACE STATION CREW ● ONBOARD PICTURE EVALUATION - IMAGE PROCESSING AND ENHANCEMENT DONE BY SPACE STATION COMPUTERS

EVOLUTIONARY TREND FOR SPACE STATION TEST POINTS MONITORED ON BOARD AND BY GROUND STATIONS

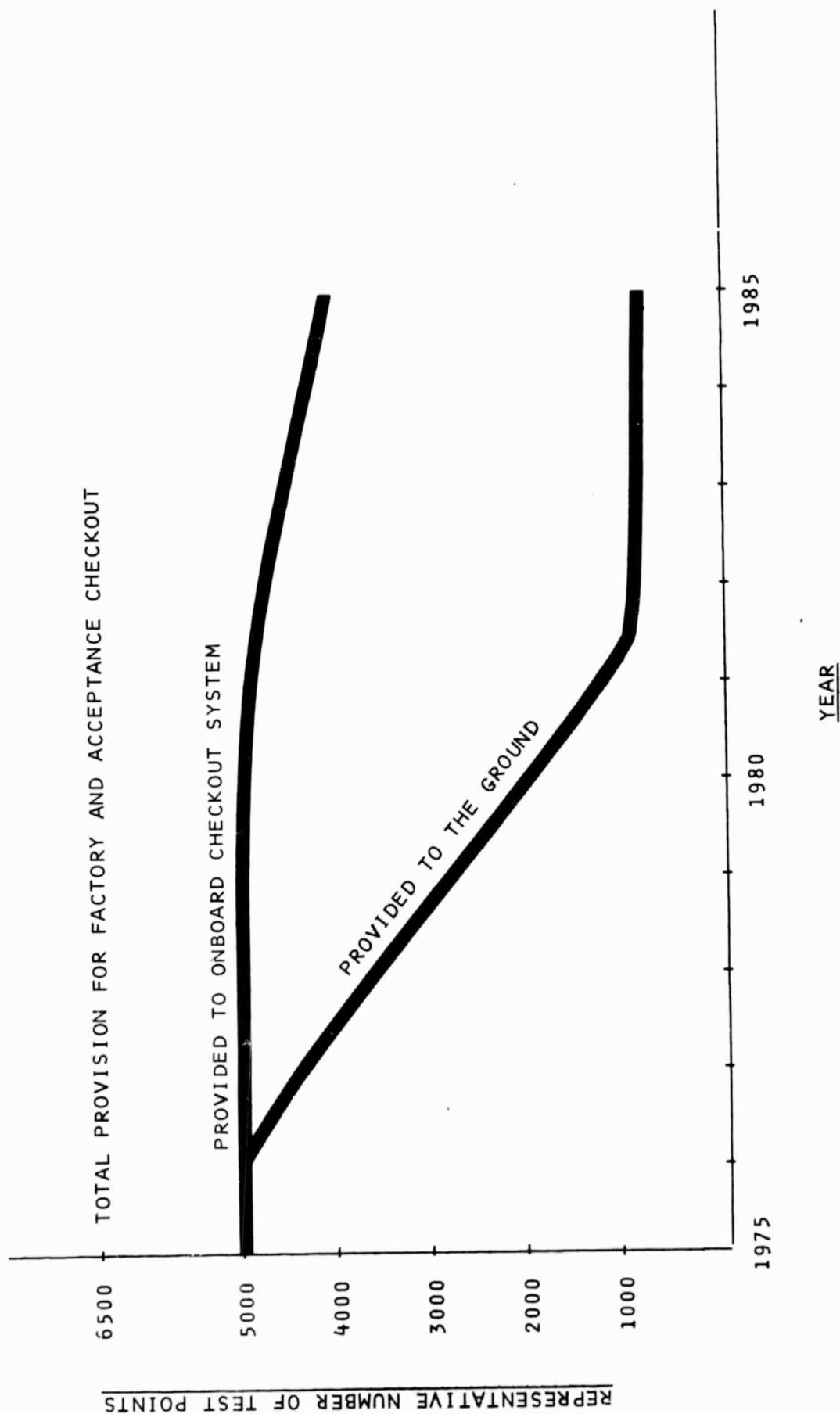


Figure 3-56. Onboard/Ground Monitoring Evolution

will be terminated. The shape of the curves reflects an estimate of how the test point monitoring trend will occur for onboard and ground systems.

The flexibility of the interface provided by using computer arranged like Concept C will make it easy to add more computing power when future modules are sent up (Table 3-50). Initially, the onboard computers will be performing primarily checkout and station keeping functions, but as more equipment becomes available the computing capability can go up enormously. At first, two systems arranged like Concept C can be tied together. Then, a third module can add another level of executive machine control and coordinate the onboard checkout activity. The same machine will also serve as an electronic data processing facility for the entire Base. Time-sharing terminals can be located in the major laboratories and experiment modules for access to the onboard computing center.

Advances in technology over the ten year Station life will greatly influence the evolution of the man/machine interface (Table 3-51). Although the initial core modules will have only two-dimensional displays, three-dimensional techniques such as holography will become available about 1980. Computer input devices will undergo little change from the keyboard and light pens available today. There will be some type of voice control and audio response available by 1985, but comprehensive vocabularies will not be feasible. There will be a significant change in the evolution of programming languages. By 1985, there will be language compilers available that will convert free-form English text into machine language. When a complete data processing facility is established onboard, there will be several members of the crew designated as center controllers in much the same way that computer operators and system engineers

Table 3-50. Evolution of Space Station Computer

1975	1985
● PROGRAMMABLE COMPUTERS FOR: - GUIDANCE - CHECKOUT - EXPERIMENT SUPPORT ● CENTRALIZED EXECUTIVE COMPUTER OPERATES IN CONJUNCTION WITH PREPROCESSORS ● EXECUTIVE COMPUTER HAS MULTIPROCESSOR ARCHITECTURE CHECKOUT COMPUTERS ARE CONVENTIONAL SINGLE PROCESSORS	● PROGRAMMABLE COMPUTERS FOR: - GUIDANCE - CHECKOUT - DATA PROCESSING - SCIENTIFIC ANALYSIS ● CENTRALIZED STATION CONTROL COMPUTER COORDINATES SEVERAL OCS EXECUTIVE MACHINES AND SERVES AS AN OFF-LINE ELECTRONIC PROCESSING CENTER ● MULTIPROCESSOR ARCHITECTURE - EXPANDED OPERATIONAL SYSTEM FOR TIME SHARING AND MULTITASKING - TERMINAL UNITS LOCATED IN ONBOARD LABORATORIES

Table 3-51. Man/Machine Interface

1975	1985
◦ Two-Dimensional Displays - Deformagrophic Tubes - Light Emitting Diodes - Plasma ◦ Graphic and Keyboard Inputs for Computer Control - Tutorial Control by Displays - Capacitive or hall-effect keyboards ◦ One crew member must have in-depth knowledge of the onboard computer system ◦ Unique programming language required that is test and control oriented	◦ Three-Dimensional Displays - Color Holography and Kinoforms ◦ Multiple Computer Control Inputs - Graphic Inputs - Automatic, system generated direct digital control - Voice control - Hall-effect keyboards and switches ◦ Several crew members designated as data processing center controllers ◦ Complete set of language compilers available including free form English text

are used in ground-based facilities now. It must be pointed out that in the initial core module, at least one member of the twelve-man crew should have a system engineering understanding of the onboard computers. This will be especially important if any kind of hardware maintenance is planned.

This table summarizes the checkout requirements for the 1975 space station experiment and vehicle subsystems. A total of approximately 4800 test measurements are required for the early space station operations. The increase in testing requirements is evidenced by the increase in experiment test measurements; approximately 1000 additional measurements by 1980 and 2500. Additional measurements by 1985.

3.4.4.5 Onboard Data Management System

In Section 3.3 the projected daily volume of 10^{10} equivalent bits of data generated by the Space Station systems and experiments includes image, biological and other sensor based data. If all of this data were in digital form and required processing by the onboard computer system, the load imposed on the system would be excessive. Similarly, the transmission of this volume of data to the ground would require a transmission rate of nearly 10^6 bits/seconds on a continuous basis.

In fact, the volume of data transmitted can be significantly reduced by physical return of photographic data and data compression. Since even a simple algorithm for compression, such as limit checking, would load the onboard computer system with routine operations, it is suggested that a separate subsystem be employed for routine data management functions.

The suggested data management system is fundamentally a part of the telemetry system, and as can be seen in Figure 3-57, the measurement conditioning and encoding is identical. However, beyond conditioning and encoding, the system becomes more complex. Since the sources of data and the operations to be performed on the data will vary with time, the data management subsystem must have a basic computational capability and must also be controllable from the onboard executive computer.

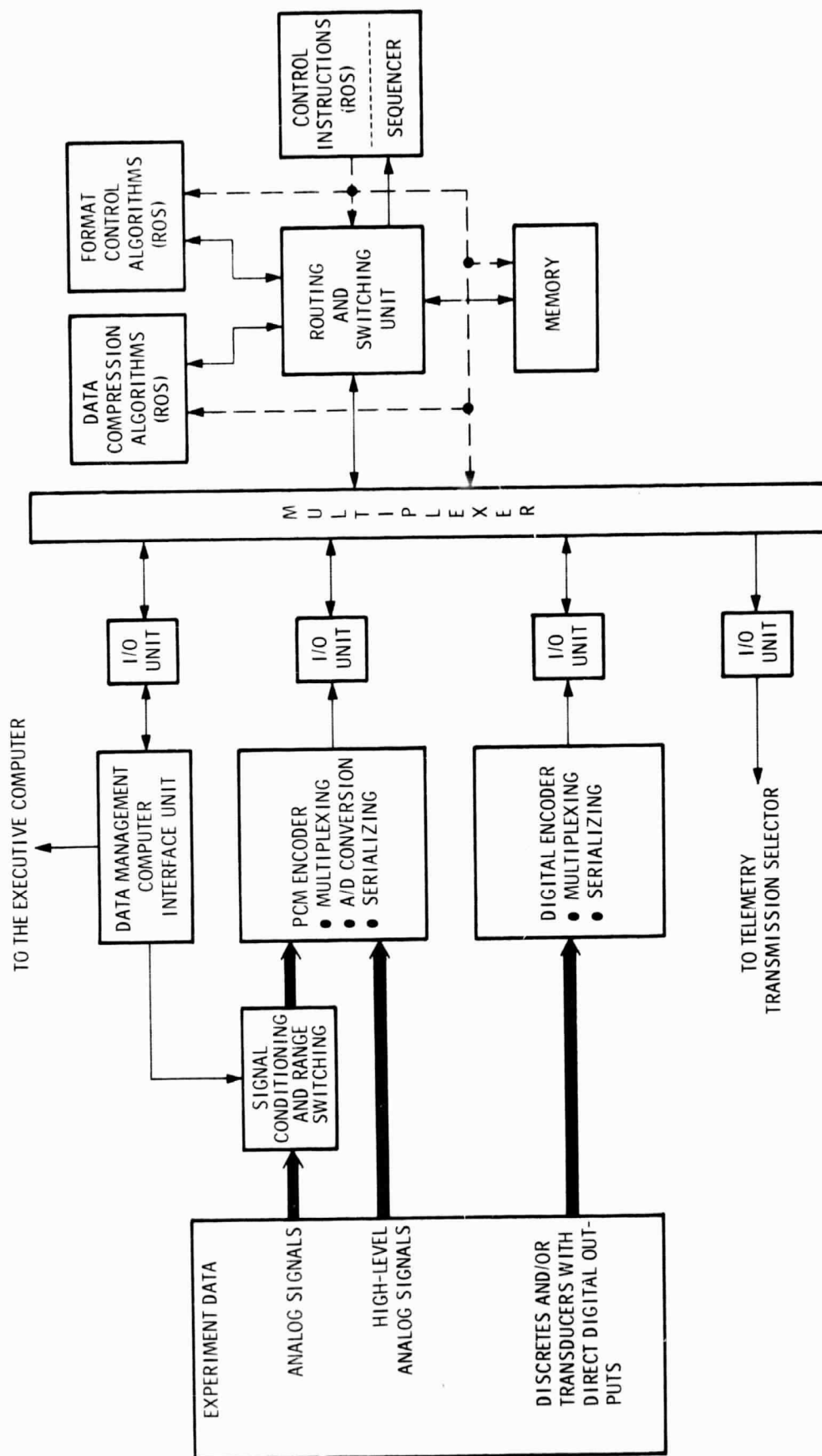


Figure 3-57. Candidate Data Management System

Computational and sequencing functions are accomplished by Read Only Storage (ROS) units combined with their own dedicated memory. Control by the onboard executive computer is exercised directly on signal conditioning and range switching and on the ROS units by setting flags in the dedicated memory if conventional ROS technology is used or by directly changing the ROS micro-program if electronically alterable ROS is available.

The major weakness in this type of data management system lies in the relative inflexibility of the microprogrammed units. The data compression and sequence control algorithms are certain to require modification as new techniques are developed and the type of data derived from the experiments changes. If such modifications require physical replacement or modification of the ROS units, additional logistics and checkout problems will be encountered. Electronically alterable ROS units would be desirable for this reason. Another possibility would be to replace the microprogrammed units with stored program computers, but this would further complicate an already complex onboard computer system.

3.4.4.6 Onboard Telemetry System

The recommended onboard telemetry system, illustrated in Figure 3-58, is a highly conventional system but differs from present space flight telemetry systems in that the data format is under external control. Flexible data formatting, while introducing an additional level of complexity, permits the system to handle the requirements of different mission phases efficiently as well as reducing the volume of data transmitted. The format generator can also add source identification tags to the PCM data streams.

Since a wide variety of data must be handled by the telemetry system in a Space Station environment, a fixed format system can result in unnecessarily high transmission volumes. Furthermore, advanced ground systems will be required to

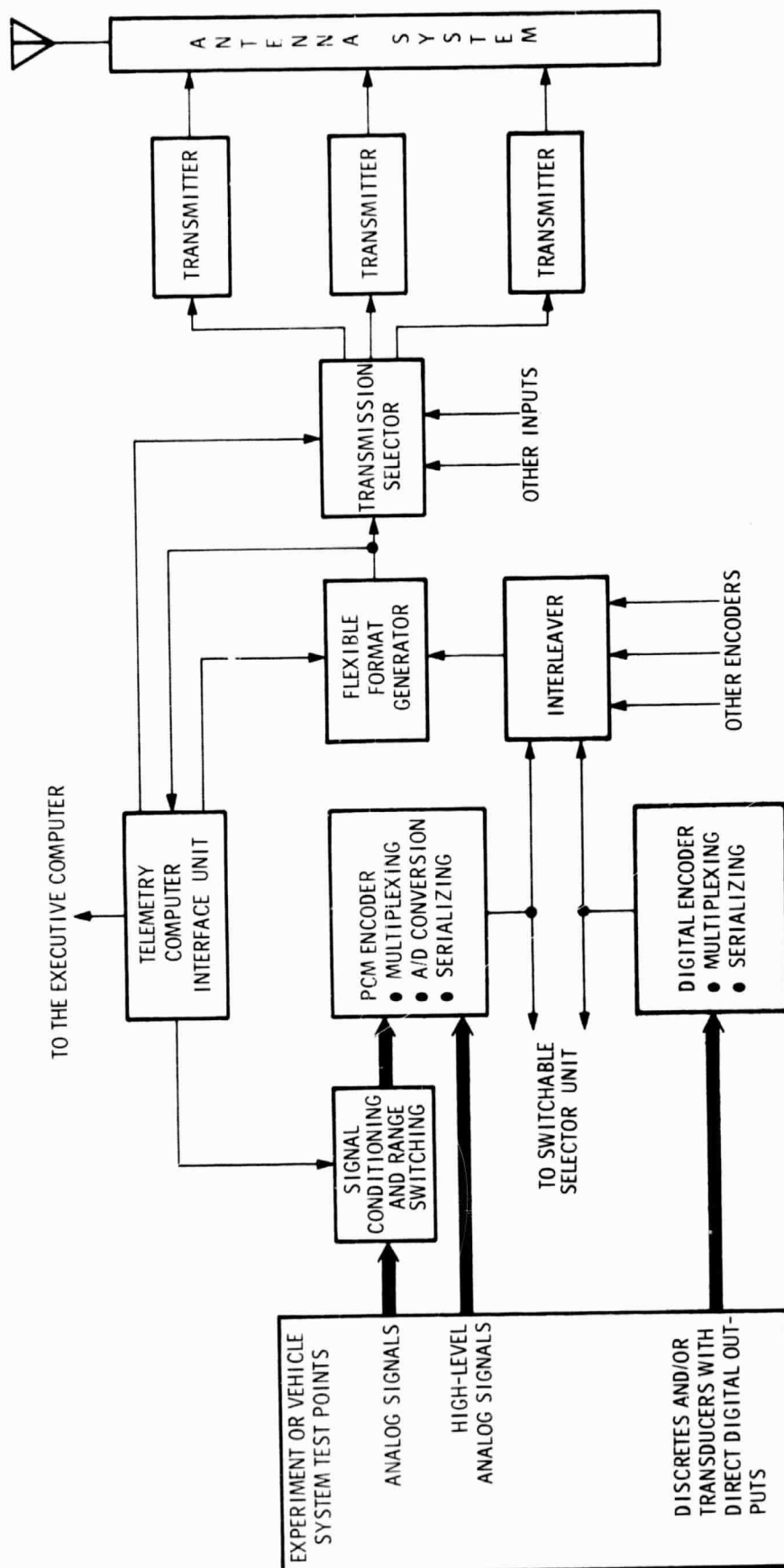


Figure 3-58. Candidate Telemetry System

handle multiple telemetry data inputs derived from concurrent missions. The onboard telemetry system can relieve the load of both the onboard and ground computer systems if reformatting and identification functions are accomplished in the telemetry system.

The format generator shown operates under control of the onboard computer system (or in turn from the ground system). Similarly, transmitter selection is controlled by the executive computer to permit bypass of a malfunctioning transmitter.

3.5 GROUND REQUIREMENTS DEFINITION

The ground system at KSC in the 1975-85 decade will perform a different role than the existing system. Instead of being dedicated to a single space vehicle, the ground system may be required to:

- o Check out complex onboard checkout systems
- o Check out launch vehicles of several different types
- o Monitor and control propellant loading
- o Perform in-orbit support functions
- o Perform experiment checkout
- o Perform greatly increased computer simulation activities
- o Support multiple missions.

The impact of some of these requirements, such as checkout of the Space Station onboard computer system prior to launch, is difficult to assess at this time because they depend on operational modes which have not been completely defined. However, there are some considerations which indicate that even the minimum level impact of the Space Station program on the ground system will be extensive.

First, the complete onboard computer system will only be available when the core module is in prelaunch preparation. Therefore, its own extensive capabilities will not be available for ground checkout of subsequent modules and experiments. Second, prelaunch testing of the onboard computer system should take advantage of the extensive data display capabilities of the ground system. Finally, the level of checkout required prior to launch may well be more extensive than the status monitoring and maintenance performed in orbit. If this is the case, then the development of checkout capabilities in the Space Station core module for complete prelaunch checkout would be uneconomical because these capabilities would be used only once and would then be duplicated in the ground system for checkout of subsequent modules.

Future missions may include a number of different launch vehicles such as Saturn I and V, Intermediate 20 and an undefined space shuttle. If each of these vehicles has a dedicated checkout and launch facility, the result will be an unnecessary duplication of ground support equipment, computer and other facilities. In addition, multiple launch crews, each trained for a particular launch vehicle, will be required.

The advent of long duration space base missions may require in-orbit ground support at locations other than the Mission Control Center. The presence of a modern telemetry receiving station (TEL IV) at Cape Kennedy makes this a logical location for support functions such as experiment data reduction or even experiment control.

Regardless of the possibility for in-orbit experimental support, final integration and testing of experiment packages will be carried out by the KSC ground system. This means that the ground system must be capable of rapid reconfiguration to handle checkout packages which are one-of-a-kind.

Because of the greatly increased complexity of the space vehicle/experiment systems, breadboard simulation techniques may not be applied as extensively as in the past. Computer simulation of space vehicle systems with automated update procedures (for incorporation of engineering changes) will be required for training, system validation and test program evaluation. Simulation at this level requires large, powerful, general-purpose digital computers particularly if the simulation is to be run in real time. One of the simulation systems employed at the MSC Real-Time Computer Complex simulates a complete Saturn vehicle and requires a dedicated IBM System/360 Model 75.

Although the existing launch facility has design capability for multiple mission support, the Apollo launch schedule has been such that multiple launches with short launch windows have not been encountered. If the requirement for in-orbit support materializes, the conflict between vehicle checkout and support functions will always be present.

These general requirements will be used to determine the characteristics of the ground system configuration recommended for KSC.

3.5.1 Ground System Characteristics

The general requirements discussed in the previous paragraph will dictate the type of configuration recommended for the ground system. It stills remains to assess the overall data handling and computing speed requirements for the ground system. As a beginning point for such an assessment, the existing ground system can be analyzed and inferences drawn as to the characteristics of a future system which would either replace or augment the existing system.

Table 3-52 shows a compilation of the present KSC computing processor capabilities. By using the data from this chart and by factoring in specific information about both the architecture and the operational mode of the

Table 3-52. Present KSC Computer Capability

COMPUTER	CYCLE (μ SEC)		WORD SIZE	CORE SIZE	DIRECT ACCESS S. D.	TAPES	I/O OTHER	ADDRESSABLE MEMORY	SPECIAL FEATURES
	#								
DEE-3 (SDS910)	1	8.0	24B	16K	NO	1 15KC	PAPER TAPE ASR 33 EVENT LIGHTS	16K	INDIRECT ADDRESSING 1 KHZ EXT. CLOCK DISCRETE SCAN
DEE-6 (SDS930)	1	1.75	24B	32K	NO	2 15KC	PAPER R/P FRANKLIN (5)	16K	INDIRECT ADDRESSING DISCRETE SCAN
RCA 110A	1	10.25	24B	32K	DRUM 8.5 MSEC	4 15KC	CARD READER PRINTER REAL-TIME F.E.	4K	I/O SPECIAL INTERRUPT FAIL SAFE DI, DO ANALOG/I/O
DDP224	1	2.1	24B	32K	NO	NO	PAPER TAPE SANDERS	32K	8 LEVELS OF INTERRUPT
GE635	1	1.0	36B	128K	DISK 225MS DRUM 8.5MS	16 83KC 12KC	CRP, LINE PRINT CRTS	262K	INTERRUPT TIMER 8 LEVELS PRIORITY INTER RELOCATION REQUIREMENTS REAL-TIME I/O
CDC 160G	2	1.5	13B	8K SHARED 48K	NO	2 DED 20KC 2 SWITCHABLE	CRP, 1000 LPM CRTS	5K	REAL-TIME CONT.
GROSS 1**		.5	24B	112K (24 BIT WORDS)	110 DRUM	11 15-20KC			
GROSS 2		.25	30B	230K	DRUMS, DISKS	11 15-20KC 16 90KC			

* NUMBER REQUIRED TO SUPPORT COUNTDOWN & LAUNCH

** NOT INCL. GE635

individual computers, it is possible to postulate a processor which in terms of raw speed and memory capability is equal to the sum of the other computers in the chart. In deriving this composite, it was necessary first to normalize the systems around a particular parameter. In this case, work size was chosen and two words sizes were used: 24 bits when the GE 635 computer was not included in the profile and 30 bits when it was included. Some of the other factors and assumptions included were: that the RCA 110A takes four cycle times to execute a single instruction where the others took two, that the SDS 930s were used to only 50 percent of capacity at peak load times, and that the CDD 160G would require two fetches to obtain a 24 bit work. Other factors such as requirements for indirect addressing, limited or extensive instruction sets and number of directly available address bits were not included.

The composite computer processor which emerged from this analysis had the following characteristics (not including the GE 635 processor):

- 600K operations/second
- 0.5 microsecond cycle time
- 24 bit word
- 144 K main memory

Table 3-53 gives a breakdown of checkout signals both uplink and downlink for the present system. These signals are broken down further by type and subsystem. If the Saturn V space vehicle (AS-506) is used as typical of today's checkout requirements, then the total space vehicle measurements is 2901. In addition to this, there are 1318 measurements from the Electrical Support Equipment (ESE). The total number of measurements is 4228.

Table 3-53. Checkout Signal Summations

	TOTAL	COMMANDS	ANALOGS	DISCRETES
ESE (S&AA, HD&LO, Q-BALL, TSM)				
A/B DDAS DOWNLINK	649	N/A	338	311
GND DDAS DOWNLINK	1070	N/A	348	722
DEE-6 DOWNLINK	2418	N/A	N/A	2418
RCA-110A UPLINK	1464	1464	N/A	N/A
RCA-110A DOWNLINK	1721	N/A	N/A	1721
HDW UPLINK	399	399	N/A	N/A
HDW DOWNLINK	295	N/A	119	176
PROPELLANTS AND GASES				
DTS UPLINK	731	731	N/A	N/A
DTS DOWNLINK	1115	N/A	100	1015
DEE-3F DOWNLINK	913	N/A	N/A	913
HDW UPLINK	77	77	N/A	N/A
HDW DOWNLINK	65	N/A	N/A	65
FACILITY (CCC)				
HDW UPLINK	146	146	N/A	N/A
HDW DOWNLINK	264	N/A	89	175
UPLINK TRANSMISSIONS - 2817 DOWNLINK TRANSMISSIONS - 8510				

Recent analysis¹ has produced a means for approximating computer speed and memory requirements based upon the number of parameters input to the system. Based upon a worse case condition in which passive monitoring, short term trend analysis, and command output (diagnostic testing) were performed, a system within 4000 input parameters must be capable of executing 200,000 operations per second (average execution time of 5 microseconds/instruction) and 200,000 words of main memory (24 or 32 bit word size). If for purposes of this approximation, a 25 percent factor is included for display control and a 30 percent factor for operating system overhead, the system now requires a raw compute speed of 310,000 operations/second and 300,000 words of main memory.

The composite processor when compared to this theoretical extrapolation has twice the operation execution rate and about one half the main memory capacity. However, the composite processor does include two 32,000 work drum storage units with an 8.5 millisecond average access time. It is interesting to note that even this very basic sizing approach points out the fact that most of the existing checkout computer systems lack sufficient main memory for efficient utilization. This conclusion has been borne out by other analyses.²

Before this comparison is carried beyond its area of validity, several other points should be made. First, the extrapolation from test points to speed and size included heavy emphasis on short-term data trending and limit checking. Short-term trending was not done for any parameters on AS-506, and limit checking was not done on all measurements. Secondly, calibration calculations and conversion to engineering units was relegated to a minor role in the extrapolation technique but play a significant part in the loading of the existing system.

In spite of these considerations, the comparison does serve to qualitatively describe the present checkout system. Taken in total and represented as a composite system, it is capable of a very high rate of operation execution. This rate of execution, in spite of main memory limitations, is higher than should be necessary for the number of parameters handled by the system. Several reasons for this condition can be identified:

- o Configuration - some system units depend on other units for input/output and can operate only as fast as that input/output.
- o Dedication - different units within the checkout system are dedicated to a particular section of the space vehicle and cannot distribute their load over the other processor as needed.
- o Redundancy - many parameters are processed by more than one system unit.

3.5.1.1 Conclusions

Table 3-54 shows a breakdown of the number of measurements derived from different space vehicle configurations. If for sizing purposes a configuration consisting of an IU, S-IVB, S-II, S-IC, a big Gemini spacecraft and ESE is selected, the total number of measurements is over 5200. Using the extrapolation technique previously discussed and adding factors for operating system overhead and display control, the theoretical processor required is one capable of 375,000 operations/second with 420,000 words of main memory (it was assumed that main memory required for the operating system does not grow directly with the number of parameters). Restated, the comparison of the present system (composite) with the projected requirement is:

Present System

Projected Requirements

600,000 operations/second

375,000 operations/second

144,000 words, main memory

420,000 words, main memory

The impact of small main memory on required processor speed still holds for higher numbers of measurements so the discrepancy between the required and existing system capability is now marked.

The most obvious conclusion to be drawn from this analysis is that future requirements can be met by adding more main memory to the existing system. However, it is not clear to which of the seven processors now employed for space vehicle checkout should be upgraded. Further, unit by unit upgrading of the existing system does not relieve the problems of redundancy and input/output limitation already mentioned.

As has been stated, the effect of future requirements on the ground system configuration will be considered. The purpose of this analysis is to determine the best cost/performance solution to future checkout requirements. Standard digital computer processors are available at this time capable of executing 1,000,000 operations/second and which include 250,000 words of main memory. The main memory can be augmented by random access devices such as disks and drums. The requirements for test and checkout of advanced space vehicles can be met by a single processor of this type. Table 3-55 is an outline of the main features of such a processor. The recommended configuration for employing this processor is given in the next Section.

3.5.2 Ground System Configuration

Up to this point, the analysis have been directed at determining the basic processor capacity required to address the checkout of a complex space vehicle.

Inasmuch as this is the basic purpose of the ground system, it is reasonable to design the system configuration around a unit capable of performing this task. However, the ground system may be required to perform functions beyond that of space vehicle checkout. Whether the system is capable of performing these additional functions with a minimum impact on the basic system design is a function of the configuration of the ground system. The efficiency with which the logic and arithmetic capabilities of the computer system can be employed is also a function of the amount of data available to the processors.

The instruction rate and memory capacity previously derived need not reside in a single processor. It could be split among a number of smaller processors (as is the case with the present system). On the other hand, there are processors available today which exceed, in speed, the requirements so far identified. Large core memories with cycle times of 4 microsecond/word and in sizes of one megaword and larger are available to supplement the faster main memories of these processors. It is possible to obtain a single computer unit with double the required capacity in terms of instruction rate and memory size.

When space vehicle checkout is the only consideration, a system which employs few or no general purpose processors could be procured. Each vehicle subsystem could carry its own built-in test and stimulus equipment which in turn could be serviced by a set of hardwired logic units. In a system of this type, only data display would be handled by a general purpose computer.

These last two possibilities represent the extremes in the two basic approaches to a ground system configuration: centralized and decentralized. In the centralized system, all data is processed by a single large unit, and in the decentralized system each function is serviced by a dedicated set of checkout equipment.

Table 3-54. Measurements

	PRELAUNCH CHECKOUT	ONBOARD CHECKOUT	ONBOARD STIMULI
● <u>SPACE VEHICLE I:</u>			
- CM	441		
- IU	279		
- S-IVB	271		
- S-IB	325		
	<u>1,316</u>		
	TOTAL VEHICLE		
● <u>SPACE VEHICLE II:</u>			
- CM	306	149	
- LM	1,179	162	
- IU	298		
- S-IVB	278		
- S-II	533		
- S-IC	316		
	<u>2,910</u>		
	<u>1,318</u>		
	TOTAL VEHICLE		
- ESE	4,228		
	<u>4,228</u>		
● <u>SPACE VEHICLE III:</u>			
- SPACECRAFT (BIG GEMINI)			
- IU	2,500	965	190
- S-IVB	830	260	
- S-IB	1,000	200	
	<u>1,000</u>		
	TOTAL VEHICLE	<u>1,425</u>	
● <u>SPACE VEHICLE IV:</u>			
- 1980 SPACE STATION	5,330		
	<u>5,330</u>		
	TOTAL VEHICLE		
	<u>6,500</u>		

Table 3-55. Composite Processor

o CYCLE TIME	5 μ SECONDS
o WORD SIZE	30 BITS
o MAIN MEMORY	128K WORDS
o RANDOM ACCESS STORAGE	
- DRUM	1 x 10 ⁶ WORDS
- DISK	50 x 10 ⁶ WORDS
o FEATURES	
- PRIORITY INTERRUPT	
- FAIL SAFE	

Figure 3-59 is a conceptual layout of a decentralized system. Various balances between built-in and external test equipment can be employed for each stage, system, or subsystem to be checked out. The external test equipment can be either hardwired, microprogrammed, or programmable computer units. In a decentralized system, even when programmable units are used, only data from a specific stage or system is routed to the unit and only those programs designed to process data from that source are made available to the unit. Theoretically, in this configuration, the external test equipment can be chosen to give optimum cost/performance for its designated function. For example, it should not be necessary to employ general purpose computers where hardwired logic is adequate. Where programmable units are used, they can be sized accurately and programmed for maximum efficiency.

Figure 3-60 illustrates the concept of a conventional centralized system. In a system such as this, most of the logical and arithmetic capability of the system is centered in one or more general purpose digital computers. Unlike the decentralized system, the computers are functionally interchangeable and checkout programs for any data type are available to, and can be run on, any of the processors. To this extent, the processors can perform completely general functions; however, this configuration does not guarantee that all data is available to all processors. Processors may receive data by more than one route as is the case with the RCA 110As in the present system. Similarly, processors may output data to certain specified display or recording devices so that in effect even a general purpose computer becomes dedicated to a particular set of input data and to a particular set of display devices.

This type of system is illustrated precisely by the ground system configuration now used in the firing rooms. Even though the systems in each Firing Room are

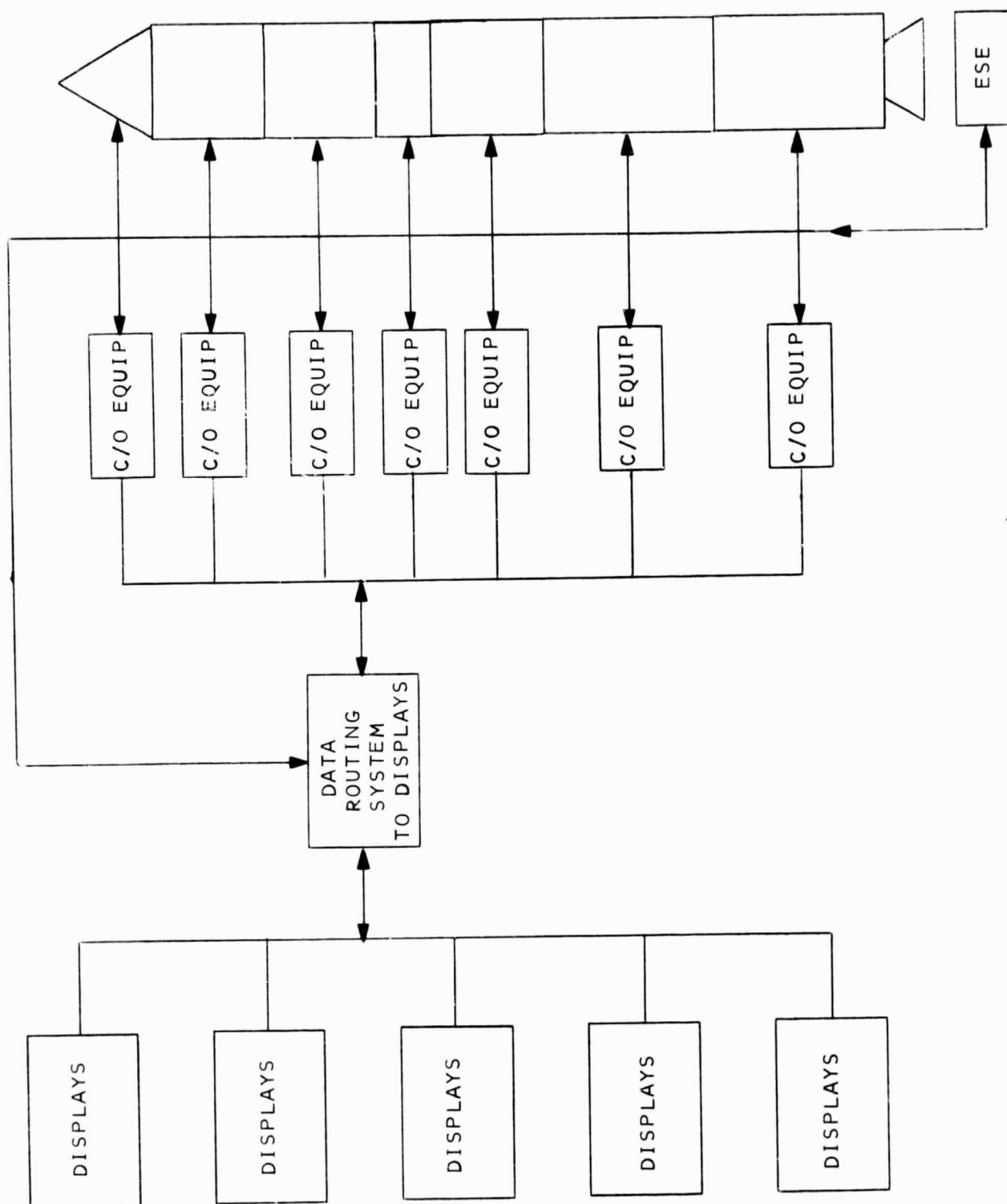


Figure 3-59. Decentralized System

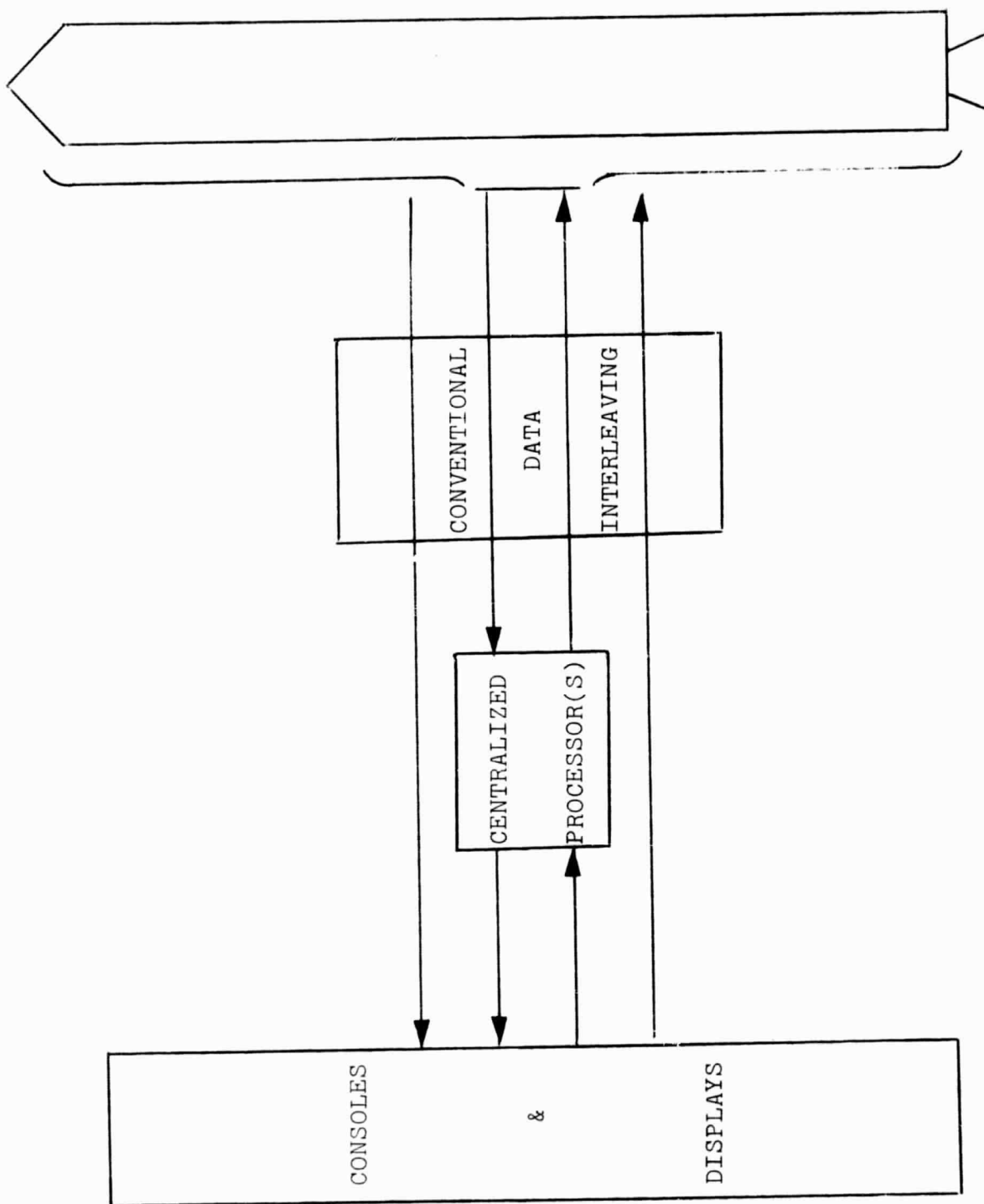


Figure 3-60. Conventional Centralized System

identical, the firing room 2 equipment cannot process data intended for firing room 1, nor can it drive the displays located in firing room 1 even though the displays are identical.

Typical methods for rerouting data or reconfiguring display systems is by means of patch panels or relay racks. The system can, in the event of failure of one of the central units, be reconfigured to bypass the failed unit. Whether electrical switching or manual switching is used is a function of the balance between the cost of the system and the time available for switching.

In a totally centralized system, all processors should have access to all data input to the ground system and should be able to drive all operational displays and recorders. The control consoles in such a system should have the ability to reroute data, reassign display functions and to redesignate the control consoles themselves.

The importance of easy and rapid reconfiguration of the ground system becomes apparent when the overall functions of the ground system are considered. In a previous section, a number of very probable functions for the ground system are enumerated. If any two of these, such as experiment checkout and launch vehicle checkout, are to be done using the same ground system, the standard question of single versus multiple sets of equipment arises. The display consoles are a typical case. From an economic standpoint, it is evident that one set of displays should serve both types of checkout. Yet this cannot be done unless data from experiments and stage data can be made available to the same set of consoles. Beyond this, it should be possible to devote some consoles to experiment checkout and some consoles to stage testing at the same time, and to change the functional ratio whenever desired.

As the previous discussion has indicated, the ability to reconfigure the system does not involve the computer processors themselves and much as it does the external data routing equipment. Figure 3-61 illustrates one approach to this problem based on a routing and switching unit which handles all data within the ground system. The data identifier system is a centralized system but differs from the conventional centralized system in that the data can be routed to or from any processing unit to any console or display under program or console operator control. The data identifier unit and the data routing and switching unit depicted in this figure perform functions identical to that of a programmable decommutator. Programmable decommutators have been used in other systems at KSC, notably the ACE system. A more detailed description of the data identifier system is given in a later paragraph.

3.5.2.1 Preferred Approach

Table 3-56 shows a comparison of the characteristics of the decentralized, conventional centralized and data identifier systems. Because of the specialized nature of the checkout equipment employed in a decentralized system, any new checkout functions require additional checkout equipment. Spares for each of these specialized pieces of checkout equipment must be carried and maintenance problems are increased. With a decentralized system, it is also difficult to use any of the equipment for more than one purpose. Configuration control problems are multiplied because each checkout system is developed independently.

The conventional centralized system and the data identifier system are seen to have similar advantages and disadvantages. However, the data identifier system offers very rapid system reconfiguration. The ability to switch system application from one type of checkout task to another is of primary importance when

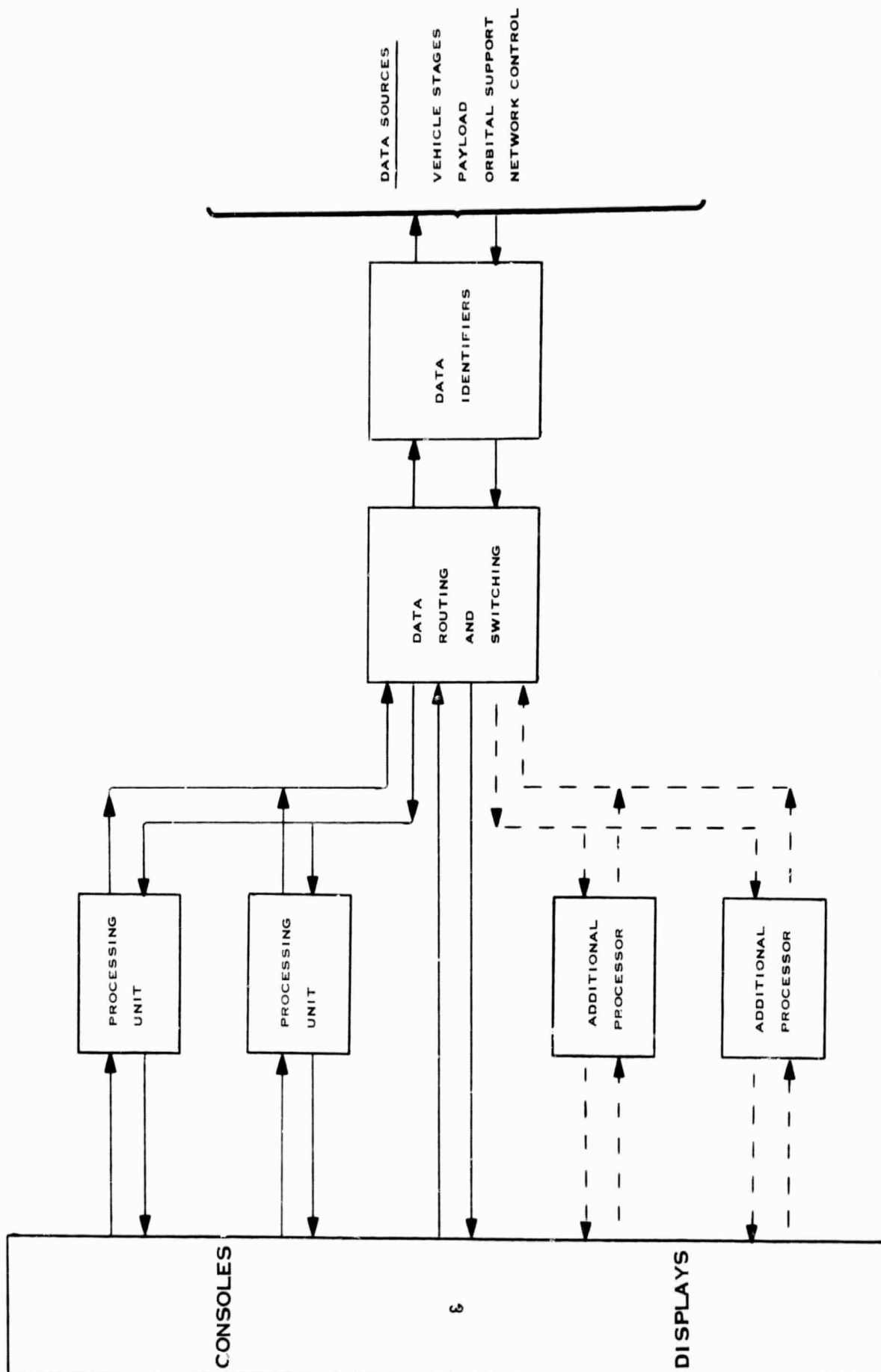


Figure 3-61. Data Identifier System (Simple)

Table 3-56. System Characteristics

Decentralized	Conventional Centralized	Data Identifier
- o Multiple checkout equipment types - o Backup requires duplication of each dedicated system - o Change in functional load requires change in configuration	- o Checkout by single processor type - o Backup requires duplicate processor operation - o Basic system capability limited to capacity of individual processors - o System turn-around limited by manual operation - o System growth can require additional interface equipment	- o Checkout by single processor type - o Rapid switching permits other use of backup processor - o Basic system capability limited to capacity of individual processors - o System turn-around under program control - o Interface equipment can include growth capability

support for multiple missions, in-orbit support concurrent with vehicle checkout, and other multiple tasks are considered. It is also possible that the rapid switching between the primary checkout computer and a back-up computer will permit other applications to be run on the back-up system without impairing its ability to take over the primary checkout process should the main checkout processor fail. Flexible use of control consoles, previously mentioned, can also be accomplished by use of an electronically switchable routing system. Since the data identifier system satisfies most of the requirements set for a future ground system, it is the recommended approach.

Figure 3-62 offers a more detailed look at the method employed in the data identifier system for routing data between data sources and computers, consoles, displays, and the vehicle. Incoming data is tagged upon receipt with a functional ID which describes the data as to type and record length. When the incoming data is received at the data routing and switching unit, a table search is made to determine if the function identification is valid. At the same time that the validity of the functional identification is checked, a destination address for that data is also obtained. Once the destination address is known, the necessary route is set up to transfer the incoming data to the appropriate destination. This destination can be either one of the computing units or one of the consoles, displays or a recording devices. For data being output from one of the computing units, a similar process is followed except that the functional identification is appended to the message by the computer itself, or an input/output unit which is a part of the I/O adapters for the consoles and displays. The verification of identification and the data destination is obtained from the output table in the same way as is done for input data. The address tables for both output and input can be updated under program control from the processors or manually from the control consoles. In this way, the

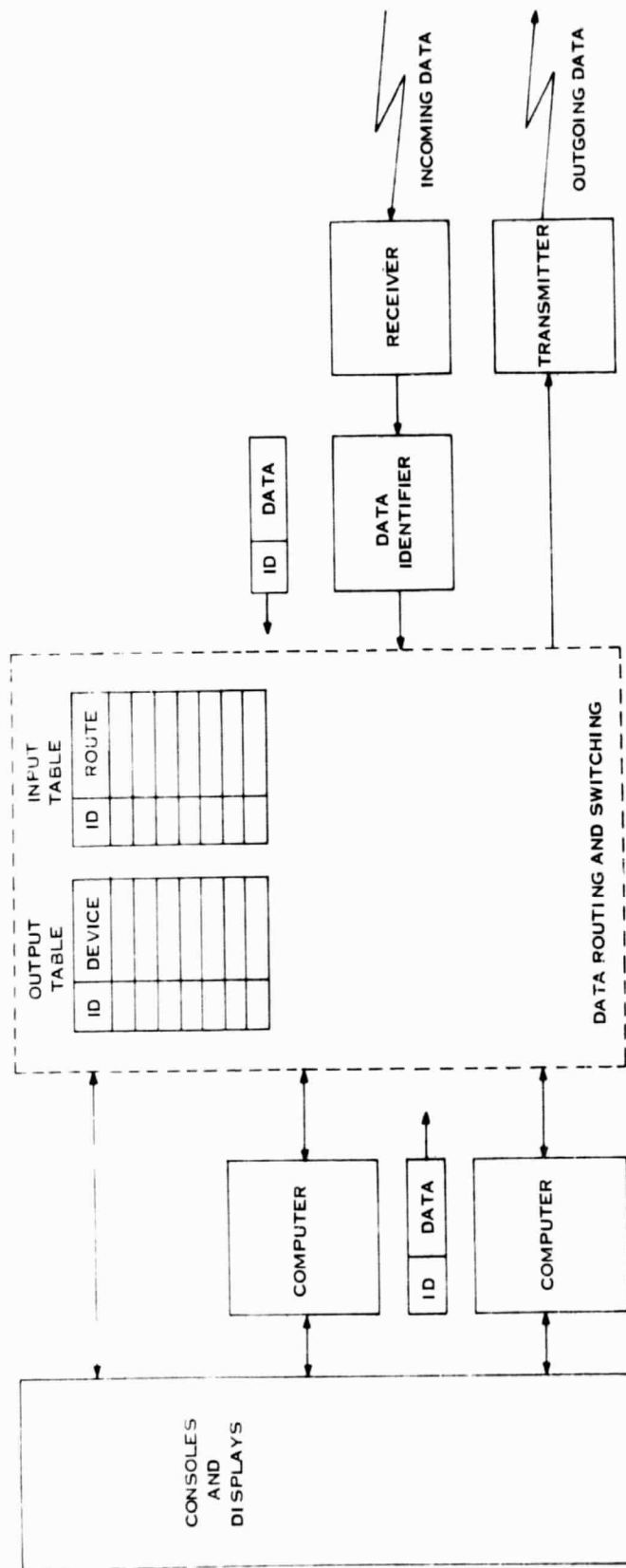


Figure 3-62. Data Identifier System B

console operator has the option of overriding the programmed address settings should that be required.

Figure 3-63 shows a detailed layout for the recommended ground system configuration. Note that, with the exception of the hardwire backup for critical functions, all other data is routed to and from the computer complex, the firing room consoles and displays, and the vehicle command system by means of the routing switching subsystem. The vehicle command system, shown on the right-hand side of the chart, differs from the existing command system in that hardwires are replaced wherever possible with RF links. The functions encoders, function selectors and stage selectors are similar to the carry-near equipment and data transmission and verification converters currently employed in the ACE system. Table 3-57 contains a summary of the data handling capabilities of a state-of-the-art routing and switching system. If the total data rate of the existing ground system including redundant paths, is calculated it is slightly over 2 megabits compared to 50 megabits for this unit.

The checkout processor layout, shown in Figure 3-64, is conventional to the extent that the stand-by processor is not used for any function other than total backup of the primary checkout processor. Backup functions are carried out in the third processor. It may be possible, through the rapid switching speed of the data identifier system, to eliminate the function of the stand-by processor and to devote it to analysis functions, such as data trending, data logging, and retrieval. Should the primary processor fail, the secondary processor, which has been performing analysis functions, can be switched in to perform the functions of the primary checkout processor. The I/O adapters, shown here, are used in conjunction with the data identifier system to verify the function ID codes which have been appended to the incoming data by the data identifier system. The data compare units perform both discrete and nondiscrete comparison functions. The

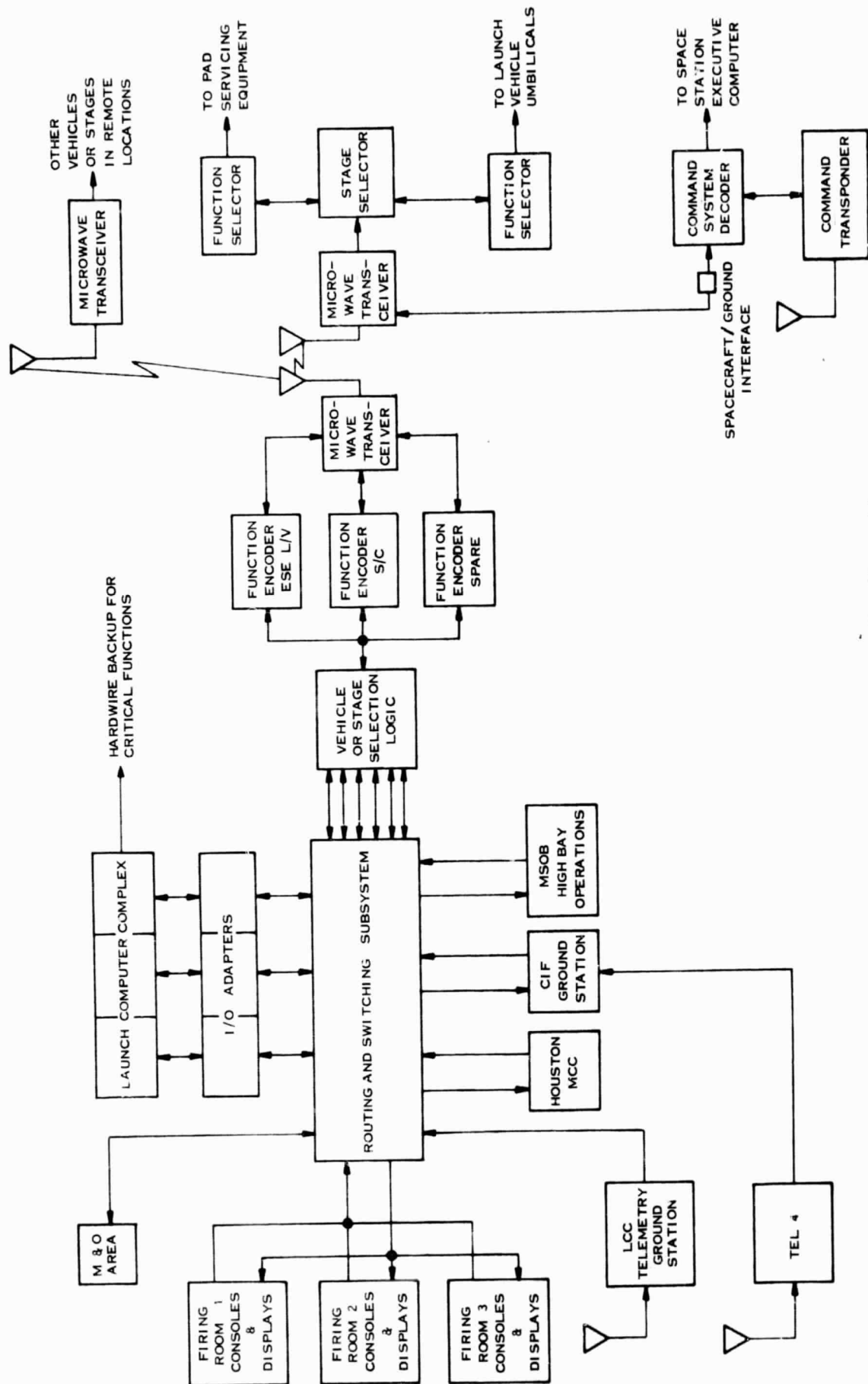


Figure 3-63. Ground System Configuration

Table 3-57. Routing and Switching Unit Characteristics

CHARACTERISTIC	DESCRIPTION
TECHNOLOGY	INTEGRATED CIRCUITRY AND SOLID LOGIC TECHNOLOGY
MEMORY	UP TO 8K 32 BIT WORDS
CPU'S SERVICED	UP TO 4
I/O ADAPTERS	28
MAINTENANCE AND CONTROL	1 MAINTENANCE AND OPERATIONS ADAPTER"
	1 TEST ADAPTER
	1 EXTERNAL CONTROL ADAPTER
DATA RATES:	
TO CPU'S	UP TO 38.4 MEGABITS/SECOND
OTHER I/O	UP TO 50.0 MEGABITS/SECOND
	50.0 MEGABITS/SECOND MAXIMUM COMBINED

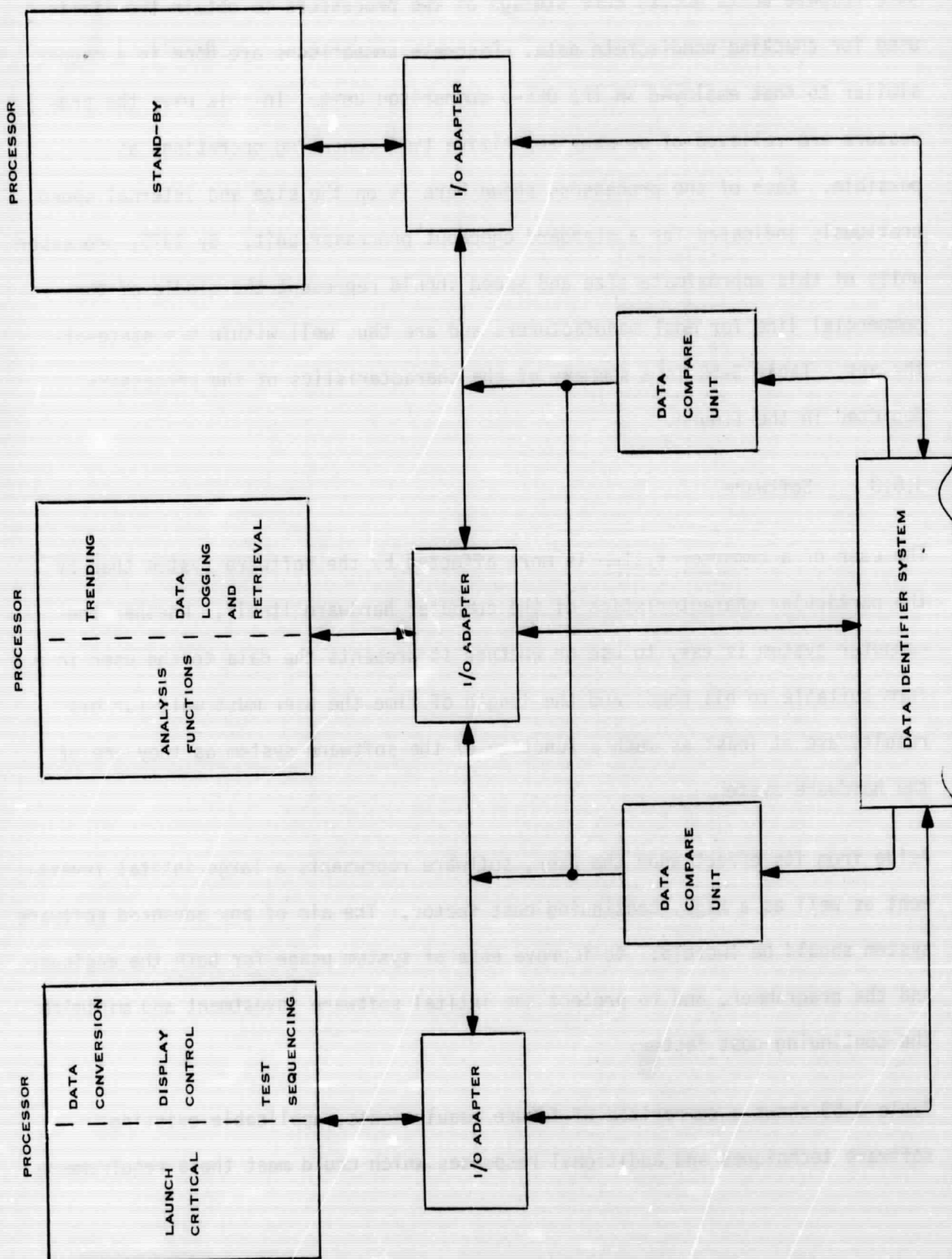


Figure 3-64. Checkout Processor Layout

data compare units access core storage of the processors to obtain the limits used for checking nondiscrete data. Discrete comparisons are done in a manner similar to that employed in the DEE-6 comparison unit. In this way, the processors are relieved of as many repetitive time-consuming operations as possible. Each of the processors shown here is on the size and internal speed previously indicated for a standard checkout processor unit. By 1975, processor units of this approximate size and speed should represent the middle of the commercial line for most manufacturers and are thus well within the state-of-the-art. Table 3-58 is a summary of the characteristics of the processors depicted in the figure.

3.5.3 Software

The user of a computer system is more affected by the software system than by the particular characteristics of the computer hardware itself. Whether the computer system is easy to use or whether it presents the data to the user in a form suitable to his needs and the length of time the user must wait for his results are at least as much a function of the software system as they are of the hardware system.

Aside from its effect upon the user, software represents a large initial investment as well as a high, continuing cost factor. The aim of any advanced software system should be twofold: to improve ease of system usage for both the engineer and the programmer, and to protect the initial software investment and minimize the continuing cost factor.

Table 3-59 shows a comparison of future requirements, applicable existing software techniques and additional responses which could meet those requirements.

Table 3-58. Computer Processor Characteristics

CHARACTERISTIC	DESCRIPTION
MEMORY, MAIN SIZE	MINIMUM 250K, 30 BIT (MINIMUM) WORDS
CYCLE	0.75 MICROSECOND
MEMORY, MASS	
DRUM	1 X 10 ⁶ WORDS AT 8.5 MILLISECOND ACCESS
LARGE CORE	1 X 10 ⁶ WORDS AT 8 MICROSECOND
DISK	50 X 10 ⁶ WORDS AT 37 MILLISECOND (AVERAGE)
INSTRUCTIONS	
SET	FLOATING POINT HARDWARE
ADD TIME	1.5 MICROSECOND
MULTIPLY TIME	4.5 MICROSECOND (FIXED POINT)
CONTROL	
PRIORITY INTERRUPT	32 LEVELS MINIMUM
PROTECTION	MEMORY PROTECT, POWER FAIL SAFE
TIMERS	EXTERNAL--1, INTERNAL MINIMUM OF 1
I/O	
MULTIPLEXER CHANNEL	1 CHANNEL - 32 DEVICES, 3.2 MEGABIT RATE
DIRECT CHANNELS	3 - 10 MEGABIT MAXIMUM DATA RATE

Table 3-59. Future Requirements and Responses

REQUIREMENT	PRESENT MODE	ADDITIONAL RESPONSE
APPLY OPERATIONAL COMPUTER CAPABILITY TO NONCHECKOUT PROBLEMS	POST-PROCESSING, ASSEMBLER LANGUAGE PROGRAMS	HIGH LEVEL ALGEBRAIC COMPILERS - FORTRAN, SPL, ETC.
IMPROVE USER ACCESS FOR TEST ENGINEERS AND PRINCIPAL INVESTIGATORS	ATOLL, ADAP, NONE FOR DEE-6, DEE-3	EXTENDED TEST LANGUAGE, CONVERSATIONAL USAGE
INTER-SYSTEM COMPATIBILITY	NONE	MAINLY HARDWARE PROBLEM - TEST LANGUAGE COULD PARTIALLY ALLEVIATE
ONBOARD/GROUND COMPATIBILITY	N/A	CONVERSATIONAL LANGUAGE COULD BE USED ONBOARD
INCREASE LEVEL OF AUTOMATION	ATOLL, ADAP	AUTOMATIC SUCCESS CRITERIA GENERATION FOR SEQUENCE CHECKING AND RED-LINE MONITORING
SIMULATION	EDS SIMULATOR, BREADBOARD	COMPLETE SOFTWARE VEHICLE SIMULATION WITH AUTOMATIC UPDATE

In general, the requirements can still be divided into two categories: improved system availability and long-term cost reduction. Given the existing hardware configuration, it is difficult to see how these two requirements can be satisfied by a purely software response.

For example, the Discrete Events Evaluator-6 (DEE-6) system has a specialized discrete scanner for input and high speed printers for output. The test engineer does not interact with the system except to force printing of variables and observing the printed output. Programming is done entirely in assembler language because higher level languages are not available to control or interact with this type of specialized input equipment. Since the DEE-6 was designed to perform high speed passive monitoring of discrete signals only, its function is completely different from that of the RCA 110s or the ACE-S/C system.

Neither algebraic nor test language compilers appear applicable to so specialized a function. Therefore, the goals of intersystem compatibility and ease of use by the test engineer are not realistic when applied to this system. Similar reasoning can be applied to other elements in the ground system to indicate that hardware reconfiguration must precede advanced software techniques which are applicable across the complete ground system.

To identify current and projected software systems which could be of use in an advanced ground system, the assumption must be made that, wherever possible, checkout functions are handled by a centralized, general purpose computer system.

3.5.3.1 Software Systems

There are a large number of software systems available today which address applications ranging from banking to nuclear reactor control. These systems can

be considered in two parts: the operating system or executive system which controls job execution and invokes the required language processors, editors, etc., and the language processors themselves.

Operating system vary greatly from vendor to vendor, and their evaluation is extremely difficult because relative capabilities are a function of the environment in which they are applied. Recommendations are made in a later section concerning steps which can be taken now to assist in accurate evaluation of any proposed operating system. Language processors can be considered to the extent of determining which may be of use at KSC and where KSC requirements are not being addressed by language developers.

Table 3-60 is a list of existing and planned language processors. This list of software systems is not intended to be exhaustive. It is intended to give examples of the various types of computer languages available for use by programmers, nonprogrammers, and system users at remote terminals. The programmer-oriented compilers are designed for use in writing complex arithmetic programs. The terminal systems are broken down into two subsections: tutorial and nontutorial. A tutorial system is one in which the user need not be familiar with the details of the system in use. Directions for system usage are displayed at the terminal to be followed by the user. In a nontutorial system, the user is expected to be familiar with the conventions of the language he is employing or the system he is using.

Of the software systems listed here, two require additional commentary: CLASP, a Computation Language for Aeronautical and Space Programming, and ATOLL, the Acceptance Test or Launch Language. CLASP is a specially designed system for use in solving guidance and navigation equations, which will be commented upon further.

Table 3-60. Software Systems - Present and Projected

- o Programmer Oriented Compilers:
 - SPL Space Programming Language
 - CLASP Computation Language for Aeronautical and
 and Space Programming
 - PL-1 Programming Language - 1
- o Remote Terminal Systems - Nontutorial:
 - CPS Conversational Programming System
 - RJS Remote Job System
- o Remote Terminal Systems - Tutorial:
 - QUIP Query/Inquiry Program
 - LGP Language Generator and Processor
 - CTS Computer Terminal System
- o Test Oriented Languages:
 - ATOLL Acceptance Test or Launch Language
- o Simulation Languages:
 - GPSS General Purpose Systems Simulator
 - SVDSS Space Vehicle Data Systems Synthesizer
 - CSS Computer Systems Simulation

ATOLL is a test-oriented compiler level language designed and implemented for vehicle checkout. It is in extensive use at KSC and is being used by engineers to write test and checkout programs. The software system survey conducted for this study did not uncover any other languages which were applicable directly to vehicle checkout or onboard checkout.

Simulation should play an increasingly important role in ground system applications. the increased complexity and variety of systems to be checked out will make breadboard or hardwired simulation difficult to the point where software only simulation is required. The simulation languages listed here address the three major areas of interest in ground system applications. The General Purpose System Simulation (GPSS) system can be used to simulate the flow of items such as spares or pieces of information through a system. Information about critical delays,, system thru-put and timelines for specific functions can be derived using GPSS models.

The Space Vehicle Data Systems Synthesizer is a simulation tool developed specifically for use in simulating vehicle systems. It combines a Boolean logic translator with the FORTRAN language to permit efficient simulation systems which are analog in nature but which are controlled by discrete relay type logic. SVDSS can be used in an on-line, interactive or stand-alone mode.

Computer System Simulation (CSS) is based upon GPSS techniques but is used specifically to model computer systems. The effects of processor speed, memory size, and I/O requirements on system thru-put can be determined for variety of system configurations by changing the system model. It is a powerful tool for evaluating either complete systems or proposed system modifications.

The Computer Language for Aeronautics and Space Programming (CLASP) represents the only NASA funded software system designed specifically for use in aerospace programming. It is, however, intended for use in solving guidance and navigation equations. That is, by use of the CLASP compiler on a standard, general-purpose digital computer, it is possible to produce programs to be run on onboard guidance computers. It is not designed for on-line or interpretive use. The language specification for CLASP does, however, include an attempt to achieve computer compatibility at the language level by specifying that the code generation segment of the compiler generator system must be replaceable. The intent is to be able to produce code which is executable on a number of different space-borne computers while using the same source computer. This requirement is based upon the need previously stated to achieve compatibility between the onboard computer system and the computer systems available on the ground.

Table 3-61 is an example of the type of tutorial display control which could be used in conjunction with the onboard computer system. The user, either by scribing the appropriate letter or by using a light pen, can call up detailed information about each of the topics listed here. As each page of detailed information appears, it is accompanied by instructions as to how to move forward or backward in the display sequence.

Figure 3-65 illustrates another possibility for system control via a remote console. The block diagram of the system to be tested would appear on the display screen at the console. The operator by means of light pen or a similar device can select the type of signal, ramp, step, etc., its value in volts or amps, and apply this signal to any of the test points shown on the diagram. After the operator has signaled "START," the selected signal will be applied at the test point; and, as an example, the RPM indicated by the rotor speed sensor will be

Table 3-61. Tutorial System Control

o To select subsystem display option, write appropriate letter:

- Guidance and navigation	A
- Life support systems	B
- Experiment groupings	C
- Maintenance records	D
- Computer system status	E

o To terminate sequence, depress tab key.

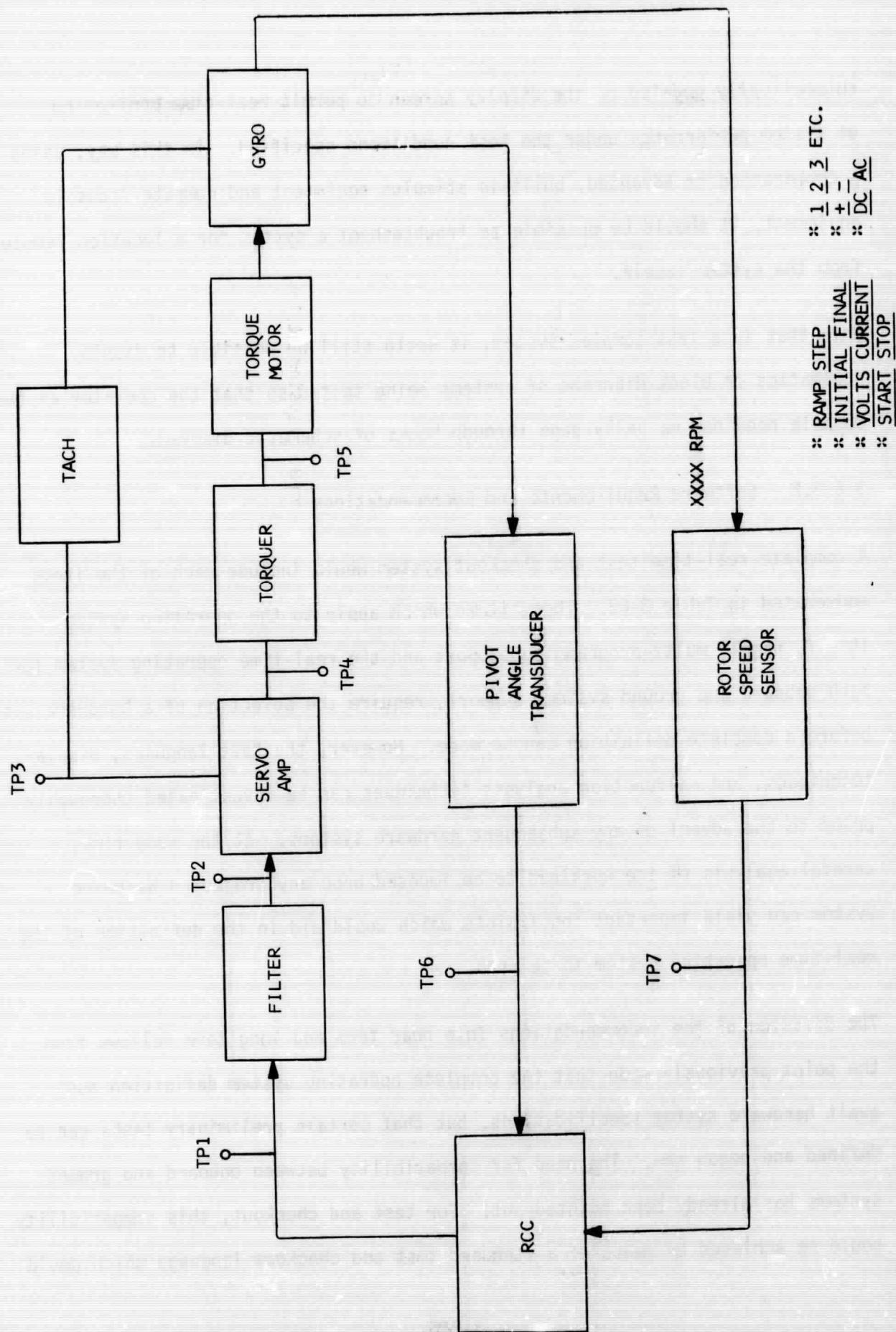


Figure 3-65. System Test Display

automatically updated on the display screen to permit real-time monitoring of system performance under the test conditions specified. In this way, using a combination of advanced, built-in stimulus equipment and computer/console equipment, it should be possible to troubleshoot a system for a location remote from the system itself.

Note that in a less complex system, it would still be possible to display schematics or block diagrams of systems being tested so that the operator at the console need not manually page through books of schematic diagrams.

3.5.3.2 Software Requirements and Recommendations

A complete real-time test and checkout system would include each of the items enumerated in Table 3-62. Those items which apply to the operating system itself, namely multi-programming support and the real-time operating system for both onboard and ground systems support, require the selection of a hardware system before a complete definition can be made. However, the test language, display techniques, and malfunction analysis techniques can be investigated thoroughly prior to the advent of any subsequent hardware systems. At the same time, careful analysis of the workload to be imposed upon any projected hardware system can yield important constraints which would aid in the definition of the real-time operating system to be used.

The division of the recommendations into near term and long term follows from the point previously made that the complete operating system definition must await hardware system specifications, but that certain preliminary tasks can be defined and begun now. The need for compatibility between onboard and ground systems has already been pointed out. For test and checkout, this compatibility could be achieved by means of a standard test and checkout language which could

Table 3-62. Software Requirements

- o A real-time test and checkout system including:
 - A test language suitable for use by engineers
 - A real-time operating system applicable to both onboard and ground system support
 - Display techniques directed at test and checkout
 - Malfunction analysis techniques
 - Multiprogramming support for data reduction and analysis.

be employed both on the ground and onboard the spacecraft. Because a ground version of the test and checkout language already exists, it is recommended that the possibility of use of this test and checkout language for the onboard system be investigated. In addition, any needed extensions to the language, which would make it more useful either on the ground or onboard, should be defined. Development of malfunction analysis routines and the extensions of the number and type of test execution programs can be undertaken using existing equipment. The data display and system control techniques illustrated in the foregoing paragraphs represent only a few of many such of a survey undertaken as part of this study, but this survey was by no means exhaustive and additional study is recommended.

Long-term recommendations deal almost exclusively with the operating system itself. The ease with which an operating system can be used is often an inverse function of the generality of the operating system. If an operating system is designed to handle all possible cases of input data, program execution type or job type, the result can be a language almost as complex as a complete programming language. If, on the other hand, reasonable constraints as to data set type, job execution type, etc., can be set, then the operating system can be made smaller, more efficient and more easily used. Finally, if the operating system implemented at KSC can be similar to the operating systems in use at other scientific computing centers, it is possible that much programming work, which has been done elsewhere, can be applied at KSC. Each of these operating system characteristics is in itself an important area for further study. If a reasonable definition of required characteristics can be achieved, considerable savings in software development can be realized over the course of the 1975-1985 decade:

o Near Term

- Begin definition phase for required onboard/ground test and checkout language
- Begin development of malfunction analysis routines
- Extend test execution programs
- Begin survey of applicable data display techniques.

o Long Term

- Define operating system specifications
 - Compatible operating system subsets
 - Trade-offs between generality and system size
 - Compatibility between KSC system and other operating systems.

3.6 IMPLEMENTATION PLANS

Before discussing any suggested plans for implementing advanced systems for KSC, it is desirable to summarize the characteristics and functions of such a system:

- o The ground system should be a centralized system built around a flexible, electronically operated data switching system.
- o The ground system must interact with complex onboard checkout systems, both for prelaunch checkout and postlaunch support.
- o Compatibility should exist between the ground system and the onboard system to ease development of onboard checkout techniques and to minimize conflicts between systems during prelaunch checkout.
- o The number of support personnel required for system operation should be minimized.
- o The ground system should serve different users with a minimum of turn-around time.
- o Prelaunch checkout should be automated to the maximum extent compatible with reliability and human back-up.

Of these characteristics, only the first deals with a purely technological, hardware question. All of the others involve either computer programs (software) or the interaction of the user with the system. The man/system interface is comprised on three parts: the hardware which he observes and operates - the control/display console, the software which governs display formats and to some extent the speed of system response, and the data available to him which is governed by the number and type of sensors and the computing power and logic capability of the ground system processors.

If the complete ground system were to be replaced at once, each of these factors and problems would have to be analyzed and solved in parallel. In many cases,

selection of one piece of hardware would dictate the characteristics of a number of other units. It would be difficult to apply all of the experience gained during the past years of the Saturn program to assure optimum system design.

Because of these factors, a highly evolutionary approach to system reconfiguration is recommended. It is possible, using modified existing equipment, to determine the feasibility of the goals previously listed before attempting to implement a new system. The existing equipment would be employed as a test bed for: new software techniques for malfunction isolation, display techniques to improve operator visibility of system performance, and test facilities for improved data handling equipment.

Table 3-63 lists the steps required for use of the SDS 930 processor as a test unit. A single SDS 930 processor would be upgraded by providing random access storage by developing a discrete and digital data interface and a Sanders Display interface. An upgraded SDS 930 system of this type could be installed in either Firing Room 3 or 4. This processor would then be used to develop software required for test and checkout as well as display control. Additional SDS 930s would then be upgraded on a one-at-a-time basis, and the checkout load transferred to this system on a phased basis.

The main advantage of this transition plan is that the basic computer hardware is available and can be used on a noninterference basis. Its primary disadvantage is that the system, once installed employing four SDS 930 processors, would have a capability about equal to the present system. In view of the cost of the effort required to develop a new system based on the SDS 930 processors, the resulting system does not represent a sufficient improvement over existing systems. This approach does permit thorough testing of the centralized system with electronic data routine and switching if a prototype switching unit is procured.

Table 3-63. SDS 930 Transition Plan

- o Develop interface for discrete out and digital data for SDS 930
- o Provide random access storage - disk or drum
- o Provide Sanders display interface
- o Develop software using single system
- o Upgrade additional SDS 930s and transfer load on phased basis.

A second possible transition plan (Table 3-64) centers about the GE 635 processors installed at the CIF. In this plan, the primary hardware emphasis would be placed upon the RF link between the CIF. The transmitters and receiver would have to be upgraded to include uplink command capability and the availability of all measurements on the downlink. The receivers at the LCC would have to be upgraded to provide interface with the LCC display equipment. Once the RF link had been upgraded as indicated, it would be then possible to develop software for the GE 635 to be used in vehicle checkout. The system could then be tested using Firing Room 3.

This is an attractive plan in the GE 635s represents large, modern computer systems with a high level of software system support. Hardware expenditures would be limited to the RF link between the CIF and the LCC. The major disadvantage of this plan is that the GE 635s are both launch mandatory items and cannot be considered to be available during CDDT and launch countdown for developmental work.

A third, somewhat more modest plan, involves only the equipment present in Firing Room 3. A scaled-down version of the RCA 110A operating system could be developed, and the system applied only to selected vehicle parameters. The resultant system would have unused capacity which could be applied to the development of an extended version of ATOLL or malfunction analysis routines.

The recommendations made here (Table 3-65) are based upon two premises: first, that a new checkout system cannot be developed without the acquisition of additional computer processor hardware; and, second, that the problem of data transmission between consoles and processors, and processors and the vehicle, and other data sources represents an area for development at least of equal importance

Table 3-64. GE 635 Transition Plan

- o Extend RF link between CIF and LCC to include:
 - Uplink command capability
 - Total downlink availability
- o Interface LCC display equipment with CIF RF link
- o Develop GE 635 software for vehicle checkout
 - Test by using Firing Room 3.

Table 3-65. Recommendations

- o Ground system should be developed in this order:
 - Data acquisition and routing system
 - Improve transmission systems
 - Software techniques development
 - Computer hardware replacement
- o Test bed for above using Firing Room 3
- o SDS 930 would serve as interim processor for test bed.

to that of the computer processors themselves. The recommendations for ground system development can, therefore, be divided into two groups. The first group consists of the first three items, that is, data acquisition, improved transmission systems, and software techniques development. These three items can be accomplished in any order, but it is IBM's recommendation that all three areas be thoroughly investigated before attempting computer hardware replacement. Software techniques can be developed and data routing systems tested using Firing Room 3 as a test bed. One of the available SDS 930 processors would serve as an interim computer processor for such a test bed.

SECTION IV

CONCLUSIONS

The following conclusions were derived from this study:

1. A substantial amount of multiprocessor computer capability can be installed in the initial Space Station Module (1975). Consideration should be given to reserving a significant portion of this capability for in-orbit developmental use, i.e., to be assigned as appropriate applications developed in the mission.
2. An onboard computer system with programmable preprocessors monitoring subsystem performance and a general purpose digital computer performing executive and backup functions is the most reasonable approach. Flexibility, redundancy and ease of accommodation of later arriving modules is thus obtained.
3. Unless Space Base module design is such that each has a "stand-alone" onboard checkout capability, substantial ground-based computer capability will be required to support Space Station/Space Base module launches. A distributed onboard checkout/data management system, wherein full capability is obtainable only in the assembled multimodule configuration, would necessitate such ground computer support.
4. A centralized ground computer complex which derives flexibility through the utilization of data bus techniques is the most reasonable approach to the launch site configuration.
5. Software, both for onboard checkout and ground, is the greatest identifiable problem area and requires early attention. The development of a flexible, standardized test and control language to accommodate systems engineers/

technicians, principal investigators and perhaps astronauts is required and can be meaningfully addressed today.

6. The operational philosophy of the Space Station/Space Base should be one of evolution. Ultimate Space Base autonomy is feasible; however, it will develop gradually with 100 percent ground backup required over the first two years.
7. As onboard capability increases, the Space Base should be used as a test facility for planetary mission equipment and should be used as the mission control facility for orbital assembly, checkout and launch. Thus, the transfer of the KSC experience and mission into orbital operations should be considered.
8. In view of the projected ten-year lifetime for the Space Station/Space Base, the key issue of high system reliability design goals versus an ease of repair/replacement philosophy, must be addressed, as well as the total fault isolation methodology question.
9. Certain technology developments necessary to optimum Space Station/Space Base systems design appear to require Governmental encouragement as commercial market pressure is not sufficient to produce a compatible maturation date. One such area is thin film bulk storage.

SECTION V

RECOMMENDATIONS FOR FURTHER EFFORT

Specific areas requiring developmental activity and further study have been uncovered during the progress of the study. They are as follows:

5.1 TECHNOLOGY DEVELOPMENT

The pressures from the non-aerospace market may not be sufficient to develop certain technologies which now appear attractive for Space Station/Space Base Application. Attention and encouragement should be directed to the following areas to ensure an adequate technology base for both the near-term and long-term missions:

- o All-electronic bulk storage
- o Ovonic technology potential
- o Parallel processor computer architecture
- o Coherent optical communication techniques
- o Real-time holographic image construction
- o Television and optical image resolution.

5.2 SYSTEMS DEVELOPMENT

Simulation technique development should be undertaken which addresses the problem of system verification for one-of-a-kind vehicles, e.g., Space Base modules. The interfaces between stages and modules as well as those between modules and ground systems warrant attention.

The development of automated malfunction isolation and trend analysis techniques for large scale systems should continue.

5.3 FURTHER STUDY

It is recommended that the system concepts developed in this study be further refined in the light of the results of the current Space Station Program Definition (Phase B) Studies. The practical limitations of onboard checkout system utilization in the prelaunch mode warrant particular attention.

The nuclear powered post-1985 Manned Mars Mission should be addressed via the same methodology applied to the Space Station/Space Base mission in this study. The potential interdependencies between the planetary modules and the Space Base should be analyzed in depth.

The extension of the study into the consideration of the potential application of the centralized ground computer complex for launch site support of a Space Station module - Space Shuttle mix is most strongly recommended. The practical limitations of the Shuttle's onboard checkout system utilization warrants attention. Potential ground computer system support, both off and on-line should be considered.

SECTION VI

REFERENCES

6.1 SECTION 3.3 REFERENCES

1. The Needs and Requirements of a Space Station Vol. 1-8, prepared by the NASA Space Station Requirements Steering Committee (no date, no number).
2. Experiment Program for Manned Orbital Workshops, August 1968, Advanced Manned Missions Program Office of Manned Space Flight Center (no number).
3. Sensor Definition Study in Support of Unified Space Applications Missions NAS5-10436, February 1968.
4. IBM Brown Book (Experiments Baseline) Report SSC 68-0614/2315.
5. ORL Experiment Program NASW-1215, February 1966.
6. "Combined Mission Requirements", D2-114013-1, NAS9-6816, The Boeing Company, Seattle, Washington, November 1967.
7. "Study of Manned Vehicles for Entering the Earth's Atmosphere at Hyperbolic Speeds" NAS2-2526, LMSC Document 4-05-65-12, Lockheed Missiles and Space Company, November 1965.
8. "Integrated Manned Interplanetary Spacecraft Concept Definition", Final Report, Volumes I-VI, NAS1-6774, The Boeing Company, Seattle, Washington.
9. "Instrument Unit Modifications for Manned Interplanetary Missions", IBM No. 67-K04-0002X, IBM, FSD, Huntsville, Alabama.
10. "Planetary Exploration Utilizing a Manned Flight System", MSC Joint Action Group Study, October 1966.

6.2 SECTION 3.4 REFERENCES

1. "Preliminary Systems Considerations for the Data Relay Satellite System (DRSS) for the Future Manned Space Stations", R. F. Filipowsky, Internal IBM Memo RFD 38, 18 February 1969.
2. "Functional Requirements for Spaceborne Computers on Advanced Manned Missions", Gruman, E. L., Schaenman, P. S., Bellcomm, Inc. Technical Memorandum, TM-66-1031-2, October 24, 1966.
3. "Preliminary Project Proposal Document Data Relay Satellite System", MSC, Houston, January, 1968.

4. "Manned Planetary Flyby Missions Based on Saturn/Apollo Systems", NAS8-18025, North American Aviation Report No. SID67-549-6-4, Vol. 6, Part IV - August, 1967.
5. "The Feasibility of a Direct Relay of Apollo Spacecraft Data Via a Communications Satellite", P. E. Schmidt, NASA TND-4048, August 1967, NASA, MSFC.
6. "Laser Communications Satellite Experiments", Perkin Elmer Engineering Report No. 8399, July 1, 1966 (prepared under contract to NASA, MSFC).
7. "Apollo Test Requirements", NPC 500-10, NASA, OMSF, Apollo Program, May 20, 1964.
8. "Flight Operations Planning and Preparation for Manned Orbital Missions", Boynton, J. H. and Kraft, C. C., Jr., AIAA Paper No. 66-904, AIAA Third Annual Meeting, Boston, Massachusetts, Nov. 29 - Dec. 2, 1966.
9. "Combined Mission Concept Evaluation", D2-114014-1, NAS9-6816, The Boeing Company, Aerospace Group, Space Division, Seattle, Washington, November 1967.
10. "Advanced Astrionics Requirements, Technology, Hardware", IRAD, 68-K05-0005, IBM Federal Systems Division, Space Systems Center, Huntsville, Alabama, May 30, 1968.
11. "Infrared Sensors for Spacecraft Attitude Control", Barnes Engineering Company, Stanford, Connecticut, Bulletin 13-051, June 1967.
12. "An Electronic Scan Horizon Sensor", Monroe, M. M., et al, Proc. 1st Symposium on Infrared Sensors for Spacecraft and Guidance and Control, May 1965.
13. "Star Tracking for Space Applications", Daehler, M., North American Aviation, Autonetics Division, Anaheim, California, May 1, 1966.
14. "KS-131 Spaceborne Star Tracker for Orbiting Astronomical Observatory", Kollsman Instrument Corp., Elmhurst, N. Y., December 1965.
15. "Digital Solar Aspect Systems", Adcall Corp., Waltham, Mass.
16. "Digital Attitude Control Signal Processor", Teledyne Systems Co., Proposal No. N-127-8, Northridge, California, October 26, 1968.
17. "On the Use of Quaternions in Simulation of Rigid Body Motion", Aeronautical Research Laboratory, Wright Air Development Center, December 1958.
18. "CMG Design Report" for U.S., NASA, Langley Research Center, Langley Station, Hampton, Virginia, Bendix Corporation, November 1, 1965.

19. "Stored Program Data Processor", IBM No. 67-K02-0014, IBM Technical Proposal, June 15, 1967.
20. "Sensor Definition Study in Support of Unified Space Application Mission", NAS5-10436, IBM, Space Systems Center, Federal Systems Division, Bethesda, Maryland, February 1968.
21. C. del Cano, Hardie, F. "CITS - An Automatic System Self-Test Tool", IBM, FSD, ESC, Owego, New York, September 1968.
22. Ligocki, J. E., "Preliminary Analysis of Requirements for Space Station Onboard Checkout Requirements", IBM, FSD, SSC, Huntsville, Alabama, October 1968.
23. _____, Study to Develop the Equations Describing the Characteristics of Rate and Attitude Sensors Associated with Spacecraft Control Systems, The Bendix Corporation, Teterboro, New Jersey, NAS1-4874, April 1966.
24. Bedford, D., Markarian, H., and Plesykoch, N., "Study of Control Computers for Control Moment Gyro Stability and Control Systems", Volume 1 (Engineering), NASA CR-66373, Langley Research Center, March 1967.
25. Morine, L. A., and O'Connor, B. J., "The Description of the CMG and Its Application to Space Vehicle Control", The Bendix Corporation, Teterboro, New Jersey, Memo No. MT-14, 101, February 20, 1967.
26. Kennel, H. G., "Individual Angular Momentum Vector Distribution and Rotation Laws for Three Double-Gimballed Control Moment Gyros", MSFC, NASA TMX-53696, January 1968.
27. Greenberg, M., "A Gravity Gradient Desaturation Scheme for the LM/ATM Mission", The Bendix Corporation, Memo No. MT-15062, June 1967.
28. Gilson, L., Irby, J., and Miller, B., "Implementation of Digital Attitude Control Functions in the Up-rated Saturn I and Saturn V Boosters", IBM Technical Memo, 69-K22-006, August 8, 1969.
29. IBM Brown Book (Experiments Baseline) Report SSC 68-0614/2315.
30. F. G. Milligan, "Computer System Requirements for the 1975 Space Station", IBM Unpublished Report, Dated December 1968.
31. Space Station Program Definition Study Statement of Work, NASA-RFP, page B-27, April 14, 1969.
32. "Instrument Unit Modifications for Manned Planetary Missions", IBM No. 67-K04-0002X, Federal Systems Division, Huntsville, Alabama, November 1967.