An Engineering Study of Onboard Checkout Techniques

FINAL REPORT

TASK 1: REQUIREMENTS ANALYSIS AND CONCEPTS

Huntsville

IBM

An Engineering Study of Onboard Checkout Techniques

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FINAL REPORT

TASK 1: REQUIREMENTS ANALYSIS AND CONCEPTS

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TABLE OF CONTENTS

Table of Contents (Cont)

Table of Contents (cont)

Table of Contents (Cont)

Table of Contents (Cont)

LIST OF ILLUSTRATIONS

LIST OF TABLES

List of Tables (Continued)

FOREWORD

This is one of a set of five final reports, each one describing the results of a task performed under Contract NAS 9-11189, "An Engineering Study of Onboard Checkout Techniques." The five reports are as follows, all dated March 1971:

Task 1: REQUIREMENTS ANALYSIS AND CONCEPTS (IBM NO. 71W-00111)

Task 2: SOFTWARE (IBM NO. 71W-00112)

Task 3: ONBOARD MAINTENANCE (IBM NO. 71W-00113)

Task 4: SUMMARY AND RECOMMENDATIONS (IBM NO. 71W-00114)

Task 5: SUBSYSTEM LEVEL FAILURE MODES AND EFFECTS (IBM NO. 71W-00115)

The nine-month study was performed by the IBM Federal Systems Division at its Space Systems facility in Huntsville, Alabama, with the support of the McDonnell Douglas Astronautics Company Western Division, Huntington Beach, California.

Technical Monitor for the study was Mr. L. Marion Pringle, Jr., of the NASA Manned Spacecraft Center. The guidance and support given to the study by him and by other NASA personnel are gratefully acknowledged.

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Acknowledgment is also given to McDonnell Douglas Astronautics Company, Western Division, Huntington Beach, California, as subcontractor responsible for definition and analysis of the following subsystems:

- Guidance, Navigation, and Control
- Propulsion
- Environmental Control and Life Support
- RF Communications
- Structure
- Electrical Power

The Engineering Study of Onboard Checkout Techniques was performed by the Electronics Systems Center of IBM's Federal Systems Division at the Space Systems Facility in Huntsville, Alabama. The members of that organization participating in the Requirements Analysis and Concepts Task are the following:

- Mr. A. P. McKinley - Task Technical Direction
- Mr. R. R. Manasek - Data Management Subsystem Definition
- Mr. H. K. Grounds - Data Management Subsystem Analysis
- Mr. D. H. Norton - Data Management Software Sizing Analysis
- Mr. E. F. Smith, Jr. - Data Management Subsystem Performance Analysis

Section 1

INTRODUCTION

1.1 OBJECTIVE

The concept of a low cost, manned Space Station (SS) or Space Base with a 10-year mission,and resupply capability via a logistics vehicle implies a requirement for an onboard maintenance capability never before encountered in space operations. Relatively short mission durations have heretofore allowed attainment of success through reliability techniques. Obviously, equipment reliability alone cannot guarantee complete success for a 10-year mission, and other approaches must be considered.

An obvious answer is to take advantage of man's capability to perform onboard repair to enhance subsystem availability. However, man's role aboard a 10-year Space Station is primarily one of scientific and research experimentation; his involvement in other activities must be minimized if the Space Station is to achieve its scientific goals effectively.

Low operational cost implies near autonomous operation. Functions performed on the ground in earlier programs must now be performed onboard to minimize the need for extensive ground support facilities and operations.

Finally, the availability of an onboard Data Management System (DMS) strongly suggests that this hardware and its associated software may be designed to perform all the data acquisition, processing and control functions needed for automated onboard checkout capability.

For these reasons, the development of a capability to perform automated onboard failure detection, fault isolation, and recovery is the most important step toward achieving extended operation in space. The objective of this task is to identify requirements and develop concepts for such a system.

1.2 TASK STUDY APPROACH

An accurate, in-depth requirements analysis is the key to successful development of an automated Onboard Checkout System (OCS) for the Space Station. Task 1 objectives were accomplished as follows:

- NASA- supplied objectives and guidelines were analyzed to determine their impact on the OCS requirements.

- A baseline configuration of each subsystem was established for study purposes, utilizing the Phase B Definition Study results as developed by MDAC and IBM and modified by NASA direction. This subtask is documented in Section 3.

- Subsystem and major component failure modes, failure effects, and failure rates were established, and subsystem maintenance concepts were developed.

- Line Replaceable Units (LRUs) were defined for each subsystem and major components thereof.

- A strategy was developed for the checkout of each Space Station subsystem by defining the checkout functions required for checkout of that subsystem, the degree of integration of these functions into the Data Management System, and definition of any special approaches required for checkout of redundant elements of that subsystem.

- A strategy was developed for the integrated checkout of the Space Stations by defining the functions required to isolate a failure to a particular sybsystem.

- Subsystems and integrated tests were defined to perform the checkout functions identified above. Measurements and stimuli required to perform these tests were identified and compiled in a Measurement and Stimulus list.

- Functional and performance characteristics required for a Data Management System to perform the onboard checkout task were defined.

Figure 1-1, Task 1 Flow, shows the relationship of the subtasks in accomplishing the total Task 1 objective and also indicates the relationship between Tasks 1 and 2.

1.3 FUNDAMENTAL DESIGN CONSIDERATIONS

The following design considerations derived from the identified guidelines and constraints documents are considered fundamental to the OCS:

- Growth - The Space Station (crew size - 12) must be capable of growth into a Space Base (crew size - 50). The OCS design must reflect this requirement by providing a flexible, adaptable, growth-oriented system.

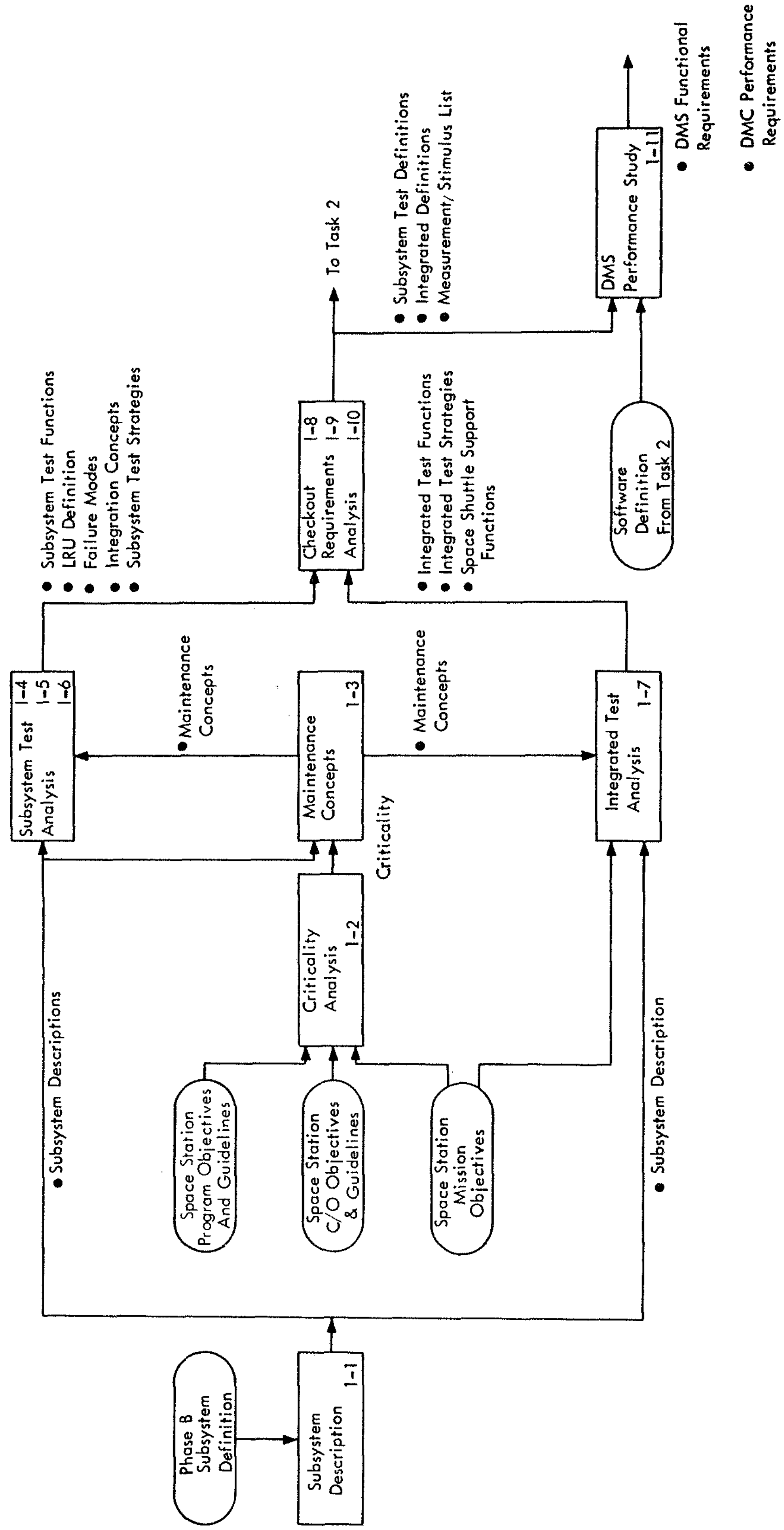

Figure 1-1. Task 1 Flow

- Operational Life - The Space Station shall be designed for a minimum operational life of 10 years with resupply of consumables and replacement items. This operational life may be obtained through long-life design, scheduled maintenance or repair, or in-place redundancy for critical or nonrepairable equipment whose failure could disable the Space Station or imperil the crew.

- Cost - A primary goal of the Space Station Program is minimizing the cost of space operations.

- DMS Functions - The DMS will provide automatic onboard fault isolation to the replaceable element and automatic onboard malfunction notification of the switchable element.

- Minimum Crew Participation - The DMS will support minimum crew participation in routine operations to the greatest practical extent. Crew responsibilities will include, where necessary, fault isolation, maintenance, calibration, and repair.

- Onboard Autonomy - All components associated with enabling the crew to recognize, isolate, and correct critical system malfunctions must be located onboard and be functionally independent of ground support and external interfaces.

- Automatic Crew Notification - All systems that incorporate an automated fail operational capability will be designed to provide crew notification and DMS cognizance of malfunction.

- Replaceable Unit Design - Replaceable units shall be designed to permit direct visual and physical access by the crew with connectors and couplings for the ease of removal and replacement.

- Baseline Data Management System - The general characteristics of the baseline DMS are as follows:

  Computer - Multiprocessor System containing two multiprocessors each with three central processing units and switching to connect any CPU to an input/output (I/O) module. Each CPU has a dedicated memory and access to all common memories. One multiprocessor shall be capable of acting as backup to the other.

  Data Bus - Digital transmission of all data except audio and video. Separate buses, implemented redundantly, are provided for command and response data.

Displays and Controls - Interactive displays with complete redundancy between two control centers.

Data Acquisition - Remote data acquisition and control with digital I/O over a serial multiplex data bus. Standby redundancy for noncritical parameters and operational redundancy (including sensors) is provided for critical parameters.

Software - High-level executive control of modular packages of software.

1.4 KEY ISSUES

Several issues which are considered key to OCS design were identified. This study has attempted to explore, at least in part, these key issues. These issues are:

- Degree of crew involvement required in the onboard checkout process
- The maximum practical degree of integration of the OCS functions with the Data Management System; i.e., allocation of OCS functions to the DMS and to other subsystems
- The role of preprocessors in the onboard checkout process
- Special problems caused by the requirement to check out redundant elements

Section 2

SUMMARY OF RESULTS AND CONCLUSIONS

2.1 GENERAL

As part of Task 1 of the Onboard Checkout Techniques Study, the onboard subsystems of the Space Station have been analyzed. From this analysis have been developed requirements for implementation of an onboard checkout capability from which checkout hardware and software performance requirements can be derived. Space Station subsystems so analyzed are:

- Guidance, Navigation, and Control
- Environmental Control and Life Support
- Electrical Power
- Propulsion
- Data Management
- Structures
- RF Communications

Summarized herein are the results and conclusions of the subsystem requirements analysis. Detailed results of the analysis are contained in Sections 3 through 7 and in Appendix I.

2.2 PRINCIPAL CONCLUSIONS

Consideration of the results of the requirements analysis and concepts definition task has led to the formulation of certain conclusions. The most significant of these conclusions are summarized in Table 2-1 with substantiating information in the indicated sections of this report.

2.3 STUDY BASELINE

A baseline configuration was developed for each of the onboard subsystems, which was to be analyzed with the goal of developing the basic requirements for the Space Station OCS. The baseline configurations selected are primarily those derived by the McDonnell Douglas/IBM study team during the Phase B Systems Definition Study. Where NASA directed, the baseline configurations include features defined by the North American Rockwell (NR)/General Electric (GE) Phase B study team. Changes to the MDAC/IBM concepts have been incorporated in the GN&C and the Data Management Subsystems. These changes were incorporated in the IBM/MDAC subsystem concept and have become the study baseline configuration.

Table 2-1. Principal Conclusions

Conclusion	Section
With the exception of parameter measurements and generation of certain unique stimuli, required checkout functions can be performed by the DMS.	5
The amount of crew time involved in the checkout process is not significant. See Task 3 report for quantitative results.	6
An allocation of checkout functional responsibility is feasible, which is compatible with the standard interface between the Data Management Subsystem and the subsystem under test.	5
No problems were identified, due to checkout of redundant elements, which required capability beyond that provided by the baseline DMS.	5
No significant checkout applications were identified for preprocessors except for hardware limit checking capability in remote data acquisition units.	6
The checkout task, in terms of data distribution and processing requirements, is compatible with the proposed DMS performance level when considering the total data management task.	8

2.3.1 GUIDANCE, NAVIGATION, AND CONTROL

The McDonnell Douglas (MDAC) Phase B concept employed a general-purpose digital computer dedicated to the GN&C Subsystem. This digital computer interfaced with the GN&C sensors and Propulsion Subsystem components through an electronic interface assembly and interfaced with the elements of the Data Management Subsystem via the data bus. In accordance with NASA direction, the GN&C Subsystem was reconfigured to include five preprocessors instead of a dedicated GN&C processor. The five preprocessors make up a family of small peripheral computers or preprocessors of a general-purpose digital design. Their performance capabilities have not been defined. The individual preprocessors interface with the GN&C sensors and Propulsion Subsystem components via individual I/O electronic modules. The five preprocessors are identified as follows:

- Optical Navigation/Attitude Preprocessor
- Inertial Navigation Preprocessor
- Rendezvous and Docking Preprocessor
- Control Moment Gyro Preprocessor
- Reaction Jet Preprocessor

All preprocessors interface with the elements of the DMS via the data bus.

2.3.2 DATA MANAGEMENT SUBSYSTEM

Significant differences between the IBM/MDAC Phase B concept and the NR/GE concept in the area of the Computer Subsystem, Data Acquisition and Distribution Subsystem, and the Onboard Checkout Subsystem are summarized in Table 2-2. In each case, the baseline to be analyzed includes the characteristics defined by the NR/MSC team.

2.4 RELIABILITY/MAINTAINABILITY ANALYSES

A logical approach to the design of an Onboard Checkout System (OCS) requires the answer to several pertinent questions including:

- What will fail?
- How often will they fail?
- How will they fail, i.e., what is the failure mode?
- How will the failure manifest itself, i.e., what is the failure effect?
- How will the failure be repaired?

To attempt to incorporate onboard checkout capability into the Space Station design without answering these fundamental questions would surely result in a "shotgun" approach, which is rarely cost effective. Therefore, prior to attempting to develop checkout strategy and define checkout tests, the following analyses were performed to provide the required answers to these critical questions.

Table 2-2. DMS Baseline Differences

Subsystem	IBM/McDonnell Douglas Concept	NR/GE Concept
Data Acquisition	• Data Terminals - Wide-Band Analog - Digital	• Data Terminals - Digital
Data Distribution	• Coaxial Data Bus - 3 Lines - Combined Command Response Lines • Redundant - Manually Switched	• Coaxial Data Bus - 4 Lines - Separate Command and Response Lines • Operationally Redundant
Onboard Checkout	• Noncritical Functions - Single Sensors and Electronics for Data Monitoring • Critical Functions - Hardwire to Central Caution and Warning Display - Local Display	• Noncritical Functions - Single Sensors and Standby Redundant Electronics for Data Monitoring • Critical Functions - Redundant (Including Sensors) into DMS via Data Bus - Local Hardwired Caution and Warning

2.4.1 CRITICALITY ANALYSIS

A criticality number (failure probability) was generated for each major subsystem component. This number is the product of: (1) the component failure rate, (2) the anticipated usage or duty cycle, and (3) an orbital time period of six months. The criticality number, then, is the failure expectation for a particular component over any six-month time period.

Overall subsystem criticality was determined by an optimization process whereby spares and redundancy are considered in terms of a tradeoff between increased reliability and weight. These overall subsystem criticality numbers which represent the complement of the probability of achieving full subsystem specified performance for 180 days are shown in Figure 2-1.

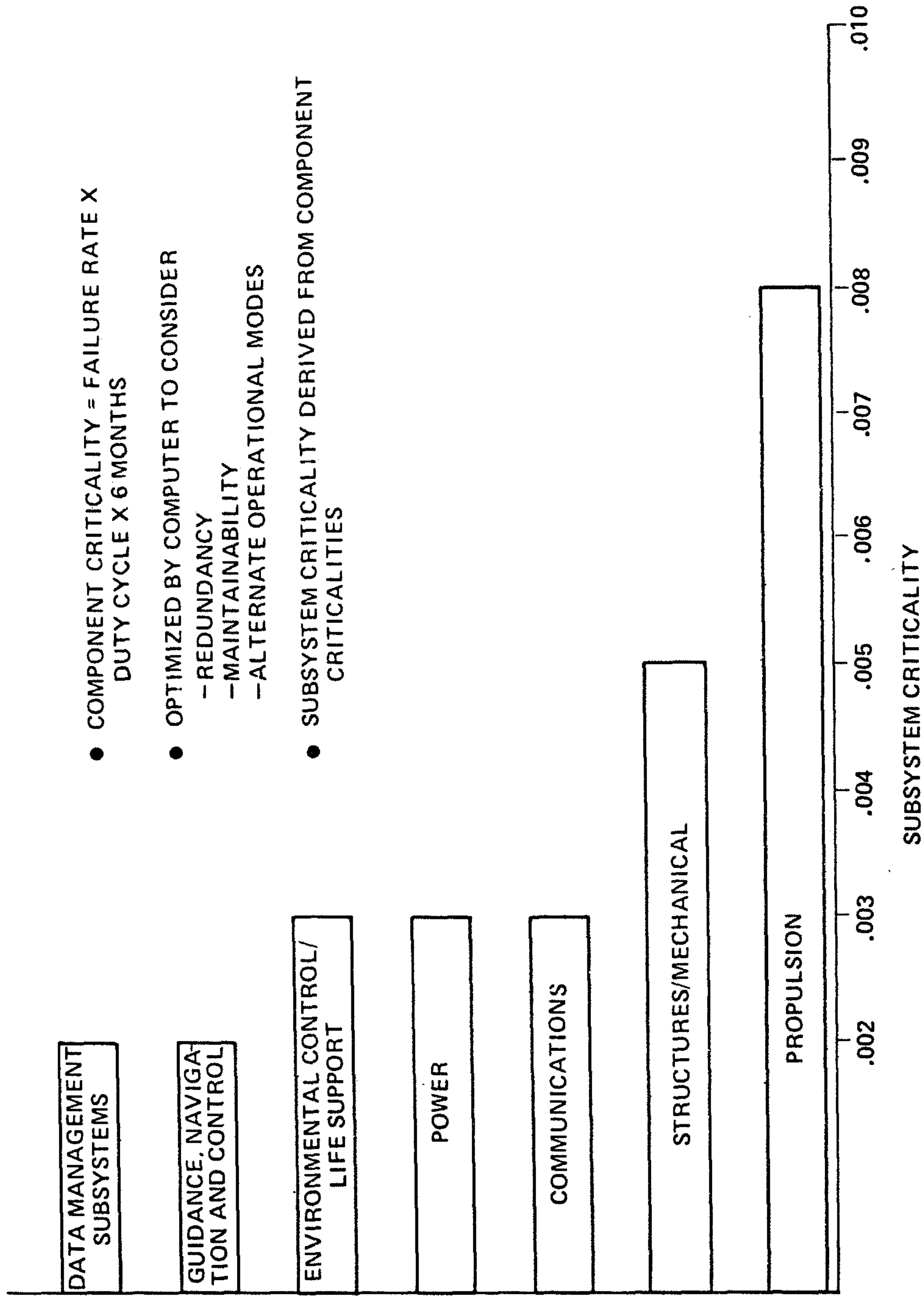

Figure 2-1. Subsystem Criticality

2.4.2 FAILURE MODE AND EFFECTS ANALYSIS

The redirected Task 5, "Reliability," will provide a more detailed failure mode and effects analysis (FMEA) for some subsystems than was possible under Task 1. The results of this FMEA are contained in the Task 5 final report.

2.4.3 MAINTENANCE CONCEPT DEFINITION

In an attempt to answer the question "How will the failure be repaired?" and to provide a rationale for the identification of line replaceable units, each subsystem was examined to determine specific maintenance concepts applicable to that subsystem. General Space Station maintenance guidelines were applied to each subsystem to develop specific maintenance concepts for that particular subsystem. These concepts are presented in Section 4.

2.4.4 LINE REPLACEABLE UNIT IDENTIFICATION

The definition of line replaceable units (LRUs) is keyed to repairing subsystems in an in-place configuration with the LRU being the smallest modular unit suitable for replacement. Factors considered in identifying LRUs were:

- Component Use
- Subsystem Maintenance Concepts
- Safety Aspects
- Component Failure Rate
- Convenient Breakpoints
- Crew Time and Skills Required
- Special Tools Required
- DMS Hardware and Software Complexity Required to Isolate to the LRU
- Physical Size

Table 2-3 is a summary of LRUs identified from each system.

2.5 CHECKOUT STRATEGY

2.5.1 GENERAL

Each Space Station subsystem was analyzed to determine the functions required to verify operational status and to detect and isolate faults within the subsystems. Then, based on the individual subsystem requirements these

Table 2-3. Line Replaceable Unit Summary

Subsystem	Types	Total
Propulsion	86	431
Structures	17	254
Communications	46	144
Power	96	1232
Environmental Control/Life Support	97	1175
Guidance, Navigation, and Control	42	154
Data Management	69	488

functions were allocated to either the subsystem side or the DMS side of the subsystem/DMS interface. Finally, a special effort was undertaken to identify special checkout problems caused by redundant subsystem elements.

2.5.2 SUBSYSTEM CHECKOUT STRATEGY

The checkout functions of stimulus generation, sensing, signal conditioning, limit checking, trend analysis, and fault isolation implemented in a combination of operational limit and validity checks and functional testing were found to be sufficient to check out the Space Station subsystems. In addition, the Data Management System requires the use of software diagnostic modules supplemented with limited measurements. With the exception of the sensing function, certain specialized stimulus generation, and pre-conditioning, all the required functions could be supplied by the baseline Data Management System.

2.5.3 FUNCTIONAL ALLOCATION

Table 2-4 shows a generalized division of functional responsibility between the subsystem under test and the DMS. The specific division of functional responsibility varies with each subsystem, and specific results for each subsystem are contained in Section 5.

Table 2-4. Generalized Functional Allocation

Subsystem Function	DMS Function
Parameter Measurement	Signal Conversion
Signal Pre-Conditioning	Command and Control
Unique Stimulus Generation	Limit Checks
Direct Limit Checks	Trend Analysis, Fault Isolation, Display

2.5.4 REDUNDANT ELEMENT CHECKOUT

The baseline Space Station subsystems were analyzed to determine the types and extent of redundancy employed in the subsystem design. Four types of redundancy were found to exist at the level of definition of the subsystem design. These are defined as:

Type I: On-line, independently operating, identical elements

Type II: Standby, non-operating elements requiring manual startup and switchover or switchover by DMS command

Type III: Standby, non-operating elements with internal (to subsystem) switchover and automatic notification to the DMS

Type IV: Functional redundancy provided by parallel, independent systems

Types I thru III can occur at the system or component level. A special case of Type I is the parallel system with isolation and cross-strapping to allow interconnection at any point in the system.

Figure 2-2 indicates the occurrence of these redundancy types by subsystem in the baseline Space Station design.

There are certain general requirements that must be considered for checkout of each of these types of redundancy. Type I, for instance, being completely independent, and operating, requires a separate set of instrumentation for checkout and additional time must be allowed for its checkout. For the special case of Type I, logic must be provided to isolate the failure and perform the proper isolation and cross-strap switching.

Subsystem	Redundancy Type			
	I	II	III	IV
GN&C	b	b		X
Propulsion	a *a b	 b	 b	
EC/LS	a *a	a b	 b	
RF	a			X
Structure	b			
Power	a *a	a b	a b	
DMS	a		a b	X

a Indicates redundancy at system level
*a Indicates special case at system level with cross-strapping
b Indicates redundancy at component level

Figure 2-2. Redundancy Usage

For Type II, provision must be made for startup and test periodically of the off-line elements to insure their operation when switched on-line. This requires application of power and checkout stimuli (if required) and dummy loads where necessary prior to acquisition of data for checkout.

For Type III, in addition to the requirements of Type II, the DMS must be capable of accepting notification of switchover and also must be capable of commanding switchover periodically to insure proper operation when required.

Type IV, as does Type I, requires separate independent instrumentation for checkout.

A special problem common to all types of redundancy is the status keeping of equipment as to whether it is off-line, on-line, failed, operating, or non-operating. For data handling systems, the handling of data arriving during a fault isolation and reconfiguration action and catch up after reconfiguration must be considered.

The application of these considerations to the individual subsystem cases is discussed in the individual subsystem checkout strategy portion of this report.

It has been concluded, as a result of this study, that the Data Management System is capable of managing the problems that arise as a result of the utilization of redundant elements in the Space Station subsystems.

2.6 TEST DEFINITIONS

2.6.1 GENERAL

Tests were defined to implement the checkout functions identified to insure the on-orbit availability of the Space Station subsystems. This definition included test descriptions, test sequencing and timing where applicable, and the measurements and stimuli required to perform these tests. For the Data Management Subsystem, a sizing analysis was performed to estimate computer execution time and memory required to perform the software diagnostics. For each subsystem, typical fault isolation routines were developed to illustrate this technique. Finally, integrated subsystem tests were defined to isolate a failure to a specific subsystem, and a typical integrated fault isolation routine was developed to illustrate this technique. The degree of crew involvement was a special consideration in the implementation of these tests. Specific results of these analyses are found in Section 6.

2.6.2 SUBSYSTEM TEST DEFINITIONS SUMMARY

For the Space Station subsystems (less the DMS) continuous critical and non-critical parameter status monitoring is used to detect faults. Periodic tests and calibrations utilizing pre-programmed routines and employing calibrated stimuli to more completely assess the health of the subsystem were defined at specified intervals. Trend analyses to predict impending failures or dangerous conditions were identified along with typical fault isolation routines. For the DMS a combination of continuous monitoring tests to detect faults and fault isolation tests to isolate faults to a specific component were defined.

For the Space Station subsystems other than the DMS, it was found that the tests were accomplished primarily by application of stimuli and measurement and processing of performance data by the DMS. On the other hand, the checkout of the Data Management Subsystem is accomplished by diagnostic software modules supplemented by certain parameter measurement.

A summary of the data requirements to implement the subsystem checkout functions is shown in Table 2-5.

It was found that the task of insuring overall Space Station availability is primarily dependent upon the proper structuring of the individual subsystem tests. The ability to test the subsystem independent of other subsystems is directly related to the number and types of interfaces between the subsystems. These interfaces must be taken into account so that erroneous or ambiguous test results will not be obtained. Therefore, before detailed subsystem fault isolation tests are initiated, a higher level of test is required to verify that all interfaces and all external conditions that influence the subsystem are proper. It was found that the number of these higher level tests is not extensive due to the approach of minimizing the different types of interfaces between subsystems. The following functional subsystem interfaces were identified:

- GNC/GMS/Propulsion
- GNC/DMS/RF Communications
- DMS/EPS
- GNC/Propulsion
- EC/LS/EPS Isotope/Brayton
- EC/LS/Low Thrust Propulsion
- EPS/Subsystem

The GNC/DMS/Propulsion interface was identified as the most complex problem for on-orbit testing, and an integrated test flow was developed for software sizing purposes.

2.6.3 DEGREE OF CREW INVOLVEMENT

The study has shown that completely automatic "hands-off" fault isolation to the line replaceable unit (LRU) is feasible in approximately 60 percent of all cases. In the remaining 40 percent, the crew involvement varies from a simple keyboard input calling up a fault isolation routine to manual fault isolation of the LRU with portable test equipment. The concept of requiring the crew member to call up the fault isolation routine in certain cases allows him to exercise his judgment as to when fault isolation and reconfiguration will occur so as not to interrupt any critical operations which may be ongoing at the time.

Table 2-5. Onboard Checkout System Data Summary

SUBSYSTEM	TEST POINTS	STIMULI	TOTALS	AVERAGE RATE (BPS) WITHOUT LIMIT CHECK	WITH LIMIT CHECK
GUIDANCE, NAVIGATION AND CONTROL	358	234	592	3,860	20
PROPULSION - LOW THRUST	244	134	378	8,940	- -
PROPULSION - HIGH THRUST	180	62	242	3,660	- -
ENVIRONMENTAL CONTROL	977	123	1,100	29,790	4,210
RF COMMUNICATIONS	455	356	801	80	- -
STRUCTURES	102	24	126	600	- -
ELECTRICAL POWER	1,157	446	1,603	15,780	5,170
DATA MANAGEMENT	304	53	357	120	30
TOTALS	3,767	1,432	5,199	62,830	9,430

Manual fault isolation is required for several failure categories. For example, leaks in the pressure shell will be isolated by the use of portable ultrasonic detectors. Leaks and blockages in fluid and gas lines cannot always be isolated by inplace instrumentation; thus, manual intervention is required.

Operational tests requiring the participation of the astronaut have also been identified. These include communication link tests where operational performance is the best indicator of link health and display tests where visual assessment of a test pattern is required.

Repair (if any) and replacement of failed components of course must be done by the astronaut.

Most of the effort identified during the study with which the crew must become involved is associated with fault isolation and periodic checks and calibrations. Although no quantitative assessment of astronaut time involving these functions was made, both functions occur relatively infrequently and are not expected to occupy a significant amount of crew time.

2.7 SOLAR ARRAY ANALYSIS

An analysis was made to determine the requirements for onboard checkout of an Electrical Power Subsystem for Space Station containing a solar panel array as the prime power generator. This effort was directed by MSC in addition to the analysis of the isotope/Brayton cycle nuclear power generator in the original study baseline. The solar array power generator analyzed is as described in DRL No. MSC T-575, Line Item B, entitled "Solar-Powered Space Station Preliminary Design," Volume II.

The approach taken to this analysis was to identify the changes in study results obtained from analysis of the original baseline due to the substitution of a Solar Array System for the Nuclear System. These changes were identified for each of the subtasks performed on the original baseline subsystems.

Revisions to component level data were required in the EC/LS, Structures, and Electrical Power Subsystems. The high temperature water interface between the EC/LS and Isotope/Brayton System was removed, elements were added to the Structures Subsystem to support the solar array power boom, and a new Power Transmission, Conditioning, and Distribution System was necessary to handle the change from an ac to dc power source. These changes, of course, required revisions to the LRU listing and the criticality analysis and FMEA.

Except for specific maintenance concepts identified for the electrical power source, the concepts defined for the isotope/Brayton configuration are also applicable to the solar array configuration.

A capability for replacing the entire Space Station power boom module is provided in the NR baseline design. The probability of utilizing this capability would be extremely remote if individual solar panels were designed for replacement. Without this feature, there is a high risk of needing a new boom before the expiration of ten years. It is recommended, therefore, that the individual solar panels be replaceable.

Changes were also required in the measurements and stimuli required to implement automatic checkout in the EC/LS, Structures, and Electrical Power Subsystems. These changes are detailed in Appendix I. Table 2-6 shows the impact of the solar array approach on the checkout data requirements.

Table 2-6. Solar Array Data Requirements

Power Supply	Measurements		Stimuli		System Total	Average Data Bus Rate (BPS)	
	Power	Others	Power	Others		Without Limit Check	With Limit Check
Isotope/Brayton	1,157	2,610	446	986	5,199	62,830	9,430
Solar Array	6,576	2,857	3,920	987	14,340	285,500	4,260

The large increase in measurements and stimuli is due to requirements for measurements and control signals to each cell of the multi-cell batteries of the Solar Array System.

An additional integrated test has been identified since active DMS control is required for orientation of the solar array panels. This function involves a DMS interface with the Electrical Power and Structures Subsystems.

2.8 DATA MANAGEMENT SUBSYSTEM PERFORMANCE ANALYSIS

The sum of the data handling and processing requirements determined from Task 1 and Task 2 was compared against the specified performance levels of the baseline Data Management Subsystem. This comparison was made to identify inadequacies in the baseline DMS. The DMS was analyzed with respect to the following conditions:

- Computer execution speed
- Memory size
- Data bus loading
- Flexibility

With respect to these parameters, no inadequacies were found to exist in the baseline Data Management Subsystem.

An area of special emphasis concerned the need for preprocessors in the DMS. Two cases were considered, i.e., the case where preprocessors already exist in the subsystem (GN&C), and the case where preprocessors would have to be added (all other subsystems). Based on the relatively light loads placed on the DMS components by the checkout task, no requirement for preprocessors was identified where none exist in the baseline subsystems. In the GN&C Subsystem where preprocessors exist for operational purposes, their presence could be used for checkout purposes to the extent that operational data is used by the checkout programs. However, this may not be cost effective due to additional software costs. A comparison of this type was not possible due to lack of definition of the proposed GN&C preprocessors, and the question remains unanswered.

A more viable option is the consideration of remote hardware limit-checking capability provided by the Remote Data Acquisition Units as a preprocessing function. Analyses have shown (Tables 2-5 and 2-6) that remote limit-checking reduces the data bus traffic where large amounts of data at high sample rates must be limit checked (Solar Array Battery data for example) and more significantly reduces the load on the central data processor at the cost of some additional hardware in the RDAU. This technique remains a preferred option although the savings in processor and data bus traffic must be traded against the hardware penalties for implementing the remote limit check capability.

Section 3

BASELINE SUBSYSTEM DESCRIPTIONS

3.1 GENERAL

This section describes the baseline Space Station subsystems which were analyzed to define onboard checkout requirements. In order to assess requirements for onboard checkout, descriptions at the subsystem level and the assembly level are required, as well as the major interfaces between subsystems.

The assembly level description for each of the subsystems (MSFC-DRL-160, Line Item 13) provided the primary working document for subsystem analysis. To reduce documentation, these documents have been incorporated by reference into this report. Therefore, where no significant differences exist from the Phase B definition, this report contains a brief subsystem description and an identification of the referenced document containing the assembly level descriptions for that subsystem. Where significant differences do exist, such as in the Data Management Subsystem, and the Guidance, Navigation, and Control (GN&C) System, the subsystem level description includes these changes in as much detail as is available. MSFC-DRL-160, Line Item 19, provided the major subsystem interface descriptions for analysis of integrated test requirements.

3.2 GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

3.2.1 SUBSYSTEM LEVEL DESCRIPTION

The GN&C Subsystem provides the following functions:

- Orbit maintenance and change control
- Zero-g operation stabilization and attitude control
- Artificial-g operation dynamics and orientation control
- Navigation
- Command and monitor of rendezvous and docking
- Experiment pointing support and positioning control

The GN&C Subsystem senses and generates the commands and data for these functions, and the Propulsion Subsystem and a part of the GN&C Subsystem (the control moment gyros) generate the actuation forces and torques for executing these functions. The sensing of Space Station position and its relative range and range rate with respect to other spacecraft are provided through the guidance and navigation functions, and the sensing of the Space Station attitude and angular rates are provided through the controls function.

The Guidance, Navigation, and Control Subsystem is shown in Figure 3-1. This subsystem consists of stellar-inertial sensors, horizon sensors, landmark trackers, range and range rate sensors, interface electronics, control logic and jet driver electronics, control moment gyros (CMGs) and associated electronics, and GN&C preprocessors.

The GN&C Subsystem must accommodate both the artificial-g and zero-g operations of the Space Station. In the artificial-g mode of operation, the GN&C Subsystem provides spin control and wobble damping of the rotating Space Station. The horizon crossing indicator sensor provides an attitude reference for the spin plane of the artificial-g mode. The attitude gyro package provides the rate signals necessary for the wobble damping function. In the zero-g mode of operation, the GN&C Subsystem provides autonomous navigation, rendezvous command, traffic control, automatic docking, and stabilization and control of the Space Station.

The autonomous navigation scheme utilizes the stellar inertial reference data and the automatic landmark tracker augmented with the drag accelerometer. The navigation is accomplished by automatically tracking known and unknown landmarks several times each orbit. The landmark tracker is similar in operation and mechanization to a gimbaled star tracker. The drag accelerometer accounts for anomalies due to Space Station orientation and docked module changes which contribute to navigation errors.

Both ground tracking and onboard subsystems will provide the navigation information for the first few years of the Space Station Program. The ground-generated data will be transmitted onboard for evaluation of the autonomous navigation system performance. As the confidence in autonomous operation is increased through this parallel operation, the ground tracking is to be phased out.

The rendezvous and traffic monitor functions are accomplished through the use of a communication/ranging system for ranges up to 1, 000 nmi and with laser trackers within 110 nmi of the Space Station. The laser trackers are gimbal mounted to provide spherical coverage around the Space Station.

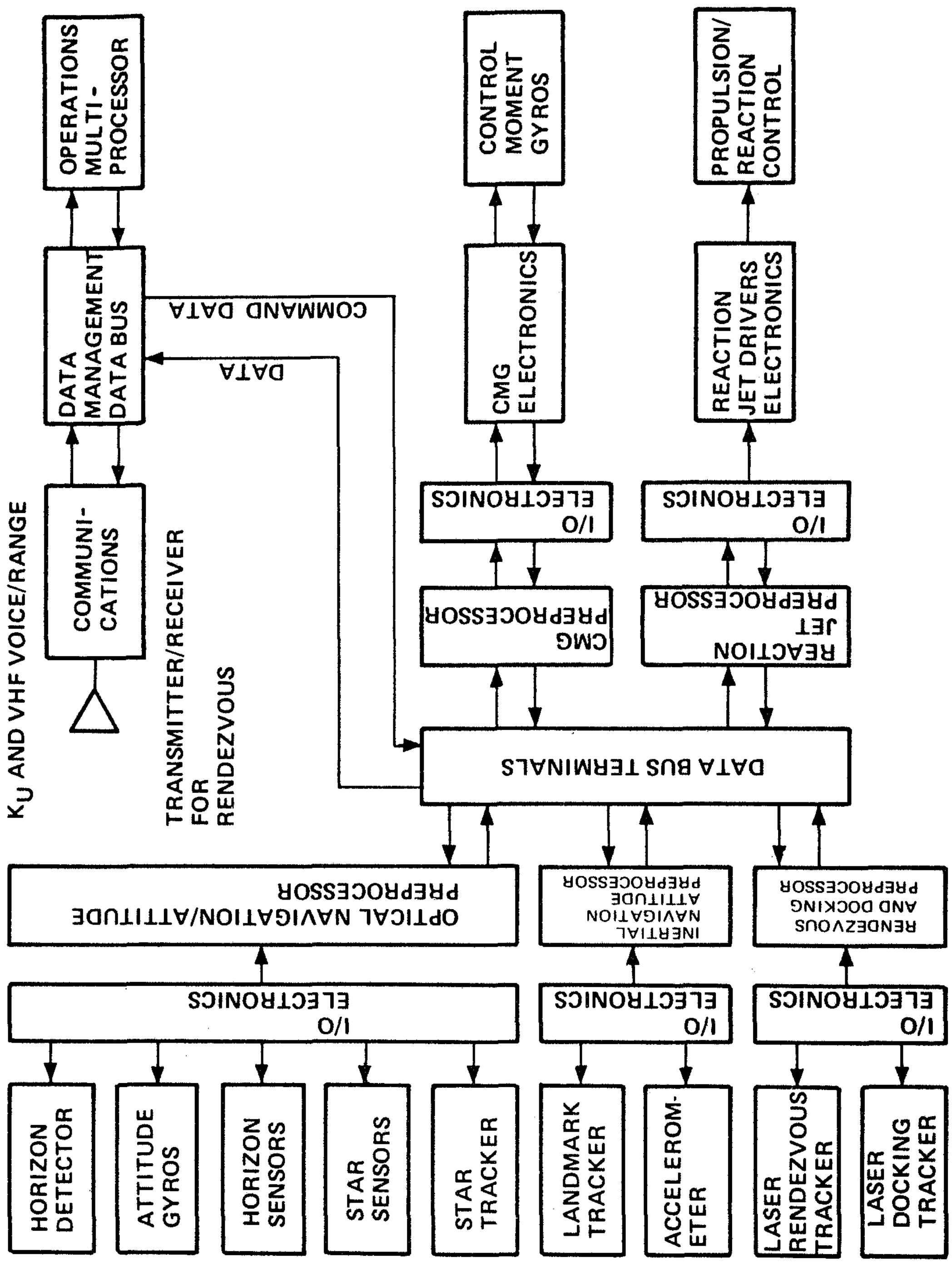

Figure 3-1. Guidance, Navigation, and Control Subsystem

For docking, each docking port is equipped with a laser docking transmitter/ receiver to provide for automatic docking capability.

Attitude and rate information for attitude control and experiment support is determined by both Earth-centered and inertial orientations.

In all operating modes and orientations, the gyros provide the high-frequency rate and attitude information necessary to supplement the data from the stellar sensors and the horizon sensors. The horizon sensors are used for initial acquisition of the Earth-referenced coordinates. They also provide a coarse Earth reference which is used when fine pointing or inertial attitude information is not required.

A more accurate Earth-centered reference is obtained in the horizontal orientation through the use of the strapdown star sensors. The star sensors provide the long-term, drift-free inertial reference data while the gyros provide the short-term, high-frequency attitude and rate information. The passive star sensors are used while the Space Station is maintained in an Earth-centered orientation. The constant rotational rate required of the vehicle to maintain this type of orientation provides the scanning motion for the star sensors, which are completely passive and provide no tracking or scanning capability of their own. The sensors themselves provide inertial attitude data which is transformed into Earth-centered attitude information by use of the navigation parameters. By this method, both inertial attitude and Earth-centered attitude are derived from the passive star sensors while the vehicle is in the horizontal or other Earth-centered orientation. This Earth-centered orientation is considered to be the most responsive to experiment and subsystem requirements.

The gimbaled star trackers are primarily utilized whenever the Space Station is required to maintain an inertial orientation. Because of the lack of angular rotation of the Space Station in this orientation, the sensors must provide their own tracking and scanning capability to acquire and track the desired reference stars.

Primary attitude control actuation is provided by control moment gyros (CMGs). A CMG configuration utilizing four double-gimbaled CMGs, each having a momentum capacity of 1,100 ft-lb-sec, was selected for the isotope/Brayton-powered Space Station. Both high and low-thrust propulsion systems are utilized by the GN&C subsystem for CMG desaturation and backup attitude control capability. The reaction jet driver electronics provide the interface with the Propulsion Subsystem.

Computational capability is provided by the Space Station operations multiprocessor and the GN&C preprocessors. The preprocessors and the multiprocessor provide the link between the sensors, which are used to determine the vehicle angular position, and the actuators, which are used to maintain or change the vehicle angular position. The GN&C preprocessors perform the necessary data formatting in addition to routine data processing for the individual sensor subsystem. The Space Station operations multiprocessor performs the data processing necessary for all guidance, navigation, and attitude control functions. The interface electronics assemblies control the flow of information from the sensors to the GN&C preprocessors and condition all sensor inputs to standardized levels. The output from the GN&C preprocessors is then routed to the operations multiprocessor via the Space Station Data Bus. The interface electronics assemblies perform a similar function for output information from the computer to the control actuators.

3.2.2 ASSEMBLY LEVEL DESCRIPTIONS

Descriptions of the GN&C Subsystem assemblies are provided in the Space Station MSFC-DRL-160, Line Item 13, Volume I, Book 4, Utility Services. These descriptions include discussions of major assemblies, physical characteristics, block diagrams, and interfaces. DRL 13, Volume I, Book 2, is incorporated by reference into this report as a detailed description of the GN&C Subsystem major assemblies and will become the primary working document for further analysis.

3.3 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEM

3.3.1 SUBSYSTEM LEVEL DESCRIPTION

The EC/LS Subsystem provides cabin atmosphere control and purification, water and waste management, pressure suit support, and thermal control for the entire Space Station.

The atmosphere is nearly that at sea level; however, in accordance with the guidelines and constraints, the system is designed to operate in a variable atmosphere of 10.0 to 14.7 psi, with a partial pressure of oxygen constant at 3.1 psi, regardless of the total pressure.

Two 12-man subsystems are provided, one for the compartment (defined as a volume of space enclosed by pressure-resistant structure) which includes decks 1 and 2, and one for the compartment that includes decks 3 and 4. The tunnel can be referenced to either subsystem.

The subsystem provided has full H_20 recovery; that is, more water is recovered in the Space Station than is required for drinking and washing. The subsystem also has partial O_2 recovery; the shortage is made up by water contained in the food.

The EC/LS Subsystem provides methane and unreacted CO_2 to the Propulsion Subsystem which uses these gases as propellants for orbitkeeping and control-moment gyro desaturation.

The total heat generated in the Space Station is rejected to space through a segmented radiator integrated with the micrometeoroid shield independently of the heat distribution between compartments.

The assemblies provided in decks 1-2 and decks 3-4 each have the capability to support 12 men. The tunnel atmosphere can be interchanged with either system through the valving and interconnecting ducting; however, the atmosphere for decks 1-2 and that for decks 3-4 are not intermixed normally through the ventilation system. Cross-linking between assemblies is provided, however, to allow one assembly to serve as an installed spare for the other.

If a major emergency occurs, such as a fire, decompression, or massive contamination, it will affect only the atmosphere in half of the Space Station. The crew will always be able to live in the other compartment within the time limit established by the amount of consumables on board at the time of the emergency. This concept also easily accommodates the 24-man crew during the overlap period. The thermal control circuits are also designed to be completely independent so that if fire disables the heat-transport loops in either compartment, it does not affect the entire Space Station.

Cooling and heating requirements are satisfied independently for each of the Space Station common modules and to minimize the probability of a full loss of the Thermal Control System. However, controls are also provided whereby these heating and cooling loads may be accommodated independently of their distribution between common modules. As a limit, either common module system can accommodate full crew and electrical loads. Because all critical electrical equipment is duplicated within the two common modules, thermal control capability is essentially duplicated. One limitation is that total available radiator area is necessary to reject total cooling loads under design environmental conditions. For this reason and because radiator failures may be difficult to repair, full redundancy is provided in the radiator circuitry. Segmentation and circuit isolation further protect against major Thermal Control System loss.

3.3.2 ASSEMBLY LEVEL DESCRIPTIONS

Descriptions of the EC/LS Subsystem assemblies are provided in the Space Station MSFC-DRL-160, Line Item 13, Volume I, Book 3, Crew Systems. These descriptions include block diagrams, discussions of assembly groups, assemblies, and major subassemblies, physical characteristics summary, and interface descriptions. DRL 13, Volume I, Book 2, is incorporated by reference into this report as a detailed description of the EC/LS Subsystem assembly group, assemblies, and major subassemblies will become the primary working document for further analysis.

3.4 RF COMMUNICATIONS SUBSYSTEM

3.4.1 SUBSYSTEM LEVEL DESCRIPTION

The Communications Subsystem comprises all equipment necessary for transmitting and receiving, tracking and ranging, command, multiple voice and television information, and broadband experiment data. The major RF subsystem equipment consists of K_u-band high gain and VHF/S-band/K_u-band low gain (omnidirectional) antennas, preamplifiers, receivers, transmitters with appropriate switching and multiplexing units, signal interface modems, and ranging unit.

The Communications Subsystem provides a radio frequency (RF) interface between the Space Station and the ground stations, either directly or indirectly, through a Data Relay Satellite System (DRSS), independent free-flying experiment modules (FFM), and logistics vehicles (LV).

The transmission and reception of television, multiple voice, and digital information between the Space Station and ground stations through the DRSS will be provided by a K_u-Band System. This link employs three uplink and downlink K_u-band RF carriers operating at frequencies between 13 and 15 GHz. The K_u-Band System consists of (1) four high-gain parabolic reflectors for normal operation, (2) transmitters and receivers, and (3) signal interface modems that sum, separate, and condition the incoming and outgoing signals.

In addition to the DRSS link, direct communications to the ground at S-band are required during the early mission phases. Uplink and downlink voice, digital data, and ranging capability will be provided by an S-band transponder compatible with the MSFN. An S-band FM transmitter is provided on the Space Station to permit an Apollo-type television signal, or wide-band real-time or stored data to be transmitted to the existing MSFN facilities. The S-band circuits transmit and receive through a low gain antenna system.

The Communications Subsystem provides the capability for simultaneously receiving up to 10 channels of video and digital data and transmitting command and ranging information from and to the FFMs at K_u-band. One of the four high gain antennas is utilized to support the FFMs while in the normal stationkeeping loop. During docking and undocking operations, the K_u-band Low Gain Antenna System provides the required coverage.

Two-way voice, data, and ranging communications between the Space Station and the Logistics Vehicles are provided by transmitters and receivers in the VHF frequency range. A Low Gain Antenna System at VHF is utilized to provide essentially spherical coverage. This system also provides voice and low data rate communications between the SS and DRSS during artificial gravity and contingency operations. Duplex voice and biomedical data reception capability from two crewmen engaged in extravehicular activity (EVA) has been provided at VHF.

The Communications Subsystem equipment has been broken down into eight assembly groups and has been grouped primarily according to function as listed below:

1. K_u-Band High Gain Antenna
2. VHF/S-Band/K_u-Band Low Gain Antenna
3. Free-Flying Module
4. Data Relay Satellite System
5. DRSS/FFM Common
6. Ground (Direct)
7. Shuttle
8. Extravehicular Activity

The RF communications assembly groups interface directly with the analog distribution bus. The operation of the subsystem is controlled by discrete commands from command decoders. Monitor and checkout information is provided to remote data acquisition units (RDAUs). Serial digital data streams are accepted from and provided to data terminals and modems which interface with the digital distribution bus. The command decoders, RDAUs and data terminals, and modems are described under the Data Management Subsystem Description.

3.4.2 ASSEMBLY LEVEL DESCRIPTIONS

Descriptions of the Communications Subsystem assemblies are provided in the Space Station MSFC-DRL-160, Line Item 13, Volume I, Book 2, Space Station Electronics. These descriptions include block diagrams, discussions of major subassemblies, physical characteristics summary, control inputs, monitor outputs, and a table of interface characteristics. DRL 13, Volume I, Book 2, is incorporated by reference into this report as a detailed description of the RF

Communications Subsystem major assemblies and subassemblies and will become the primary working document for further analysis.

3.5 ELECTRICAL POWER SUBSYSTEM

3.5.1 SUBSYSTEM LEVEL DESCRIPTION

The function of the Electrical Power Subsystem is to generate, condition, control, and distribute electrical power to the Space Station power-consuming subsystems.

This section describes the isotope/Brayton cycle EPS and specifies its characteristics, design parameters, and overall performance.

The Electrical Power Subsystem consists of four major subassembly groups:

- Power Source Assembly Group
- Energy Storage Assembly
- Power System Management Assembly
- Transmission/Conditioning/Distribution Assembly Group

The Isotope/Brayton Power System employs radiative transfer from the isotope heat source array to the Brayton cycle heat exchanger. This arrangement permits Power Conversion System (PCS) module replacement without cutting high temperature lines. The central element is the PCS-heat exchanger module, which has been designed not only for long system lifetime, but also to allow rapid changeout of a failed module.

The output of the power source assembly group is 29.8 kWe of 1200-Hz, 120/208-vac, three-phase electrical power, with 14.9 kWe provided by each PCS. The electrical power is delivered to separate source buses, which represent the initial elements of the transmission, conditioning, and distribution assembly group.

The energy storage assembly provides stored energy for following the variable vehicle power loading while maintaining constant Brayton cycle power loading, provides emergency power for a minimum of 1 hour for crew escape or Station reactivation, and provides initial power for Station activation.

The power management assembly provides control and display functions for all EPS assemblies and interfaces with the Central Control Stations, the Data Management Subsystem, and the Onboard Checkout System.

In addition to the 29.8 kWe total of electrical power, which corresponds to 25 kWe average available at the ac and dc load buses, 4.0 kWt of thermal power (2.0 kWt from each heat source) is extracted as waste heat at 250^{o}F for use by the EC/LS Subsystem. Consequently, the equivalent rating of the I/Br EPS is 25 kWe plus 4 kWe, or 29 kW at the load buses. This performance is uniquely available from this system.

The heat source is a Pu-238 isotope IRV radiantly coupled to a Brayton Cycle Conversion System generating 14.9 kWe at the alternator terminals after losses for PCS control, monitoring, and pumping.

Thermodynamic energy not converted to electricity is transferred from the Xe-He Brayton cycle working fluid to a recirculating FC-75 liquid radiator loop through a heat rejection heat exchanger. The mechanical losses of the Combined Rotating Unit (CRU) and the generator losses are transferred to a parallel cooling loop through a separate heat exchanger.

Conversion of thermal power to electrical power is performed by a recuperated Brayton cycle loop using a single-shaft CRU with a Rice alternator operating at 36,000 rpm. The indicated performance and state point conditions are established by the operating temperature ratio (heat sink heat exchanger temperature versus heat source heat exchanger temperature), and the projected PCS performance is based on extrapolation of Brayton B engine test data. PCS parasitic losses (pump and electrical power control) are deducted from the alternator output. The overall system efficiency of 25.8 percent is based on isotope heat production (end-of-life) and power available at the electrical load bus for subsystems and experiments.

3.5.2 ASSEMBLY LEVEL DESCRIPTION

Descriptions of the Electrical Power Subsystem assembly groups and assemblies are provided in the Space Station MSFC-DRL-160, Line Item 13, Volume I, Book 1, Electrical Power. These descriptions include discussions of the assembly groups and assemblies, physical characteristics, block diagrams and drawings, and design characteristics. DRL 13, Volume I, Book 2, is incorporated by reference into this report as a detailed description of the Electrical Power Subsystem assembly groups and assemblies and will become the primary working document for further analysis.

3.6 PROPULSION SUBSYSTEM

3.6.1 SUBSYSTEM LEVEL DESCRIPTION

The Space Station Propulsion System is required to perform the following functions:

- Provide attitude control, maneuvers, and docking functions prior to initial operations
- Perform spin/despin maneuvers for the artificial-g experiments
- Provide attitude control (wobble damp) during artificial-g experiment periods
- Perform orbit-keeping
- Provide control during docking maneuvers
- Provide backup attitude control

To accomplish these functions, a two-system propulsion subsystem was selected. A low-thrust, resistojet thrustor system using biowaste gases (CH_4, CO_2) as propellant will perform orbit-keeping and can, if desired, desaturate the CMGs. All other functions will be performed by a high-thrust, monopropellant hydrazine (N_2H_4) system.

The use of a biowaste resistojet system for orbit-keeping minimizes resupply, provides a useful method of biowaste disposal, minimizes contamination, and produces a near zero-g acceleration. A hydrazine high-thrust system for high torque, high impulse functions minimizes contamination and maximizes ease of maintenance.

The large quantities of propellant required for spin/despin maneuvers (6250 pounds per maneuver) prohibits initial loading, which necessitates resupply capability to be included in the design. This resupply can best be accomplished by bulk fluid transfer from the Advanced Logistic System (ALS) cargo module.

The Low-Thrust Propulsion System consists of five major assemblies:

- Collection and Storage Assembly
- Water Supplement Assembly

- Propellant Flow Control and Selection Assembly
- Thruster Assembly
- Power Distribution and Control Assembly

The High-Thrust Hydrazine Subsystem consists of seven major assemblies or assembly groups:

- High Presssure Storage Assemblies
- Pressure Control Assembly
- Propellant Tankage Assemblies
- Thruster Modules
- Resupply Assemblies
- Purge/Cleaning Assembly
- Propulsion Fault Isolation and Detection Assemblies

3.6.2 ASSEMBLY LEVEL DESCRIPTION

Descriptions of the Propulsion Subsystem assemblies and assembly groups are provided in the Space Station MSFC-DRL-160, Line Item 13, Volume I, Book 4, Utility Services. These descriptions include discussions of the major assemblies and assembly groups, block diagrams and drawings, and interfaces. DRL 13, Volume I, Book 2, is incorporated by reference into this report as a detailed description of the Propulsion Subsystem major assemblies and will become the primary working document for further analysis.

3.7 DATA MANAGEMENT SUBSYSTEM

3.7.1 SUBSYSTEM LEVEL DESCRIPTION

The DMS consists of the necessary equipment to transfer, store, and process data to and from users and subsystems. As such, it acquires and conditions a wide variety of input data from experiments, vehicle subsystems sensors, uplinked ground communications, and astronaut-activated controls.

Figure 3-2 depicts the DMS baseline configuration. Individual subsystem descriptions are provided because of the differences between the study baseline and the MDAC/IBM Phase B configuration.

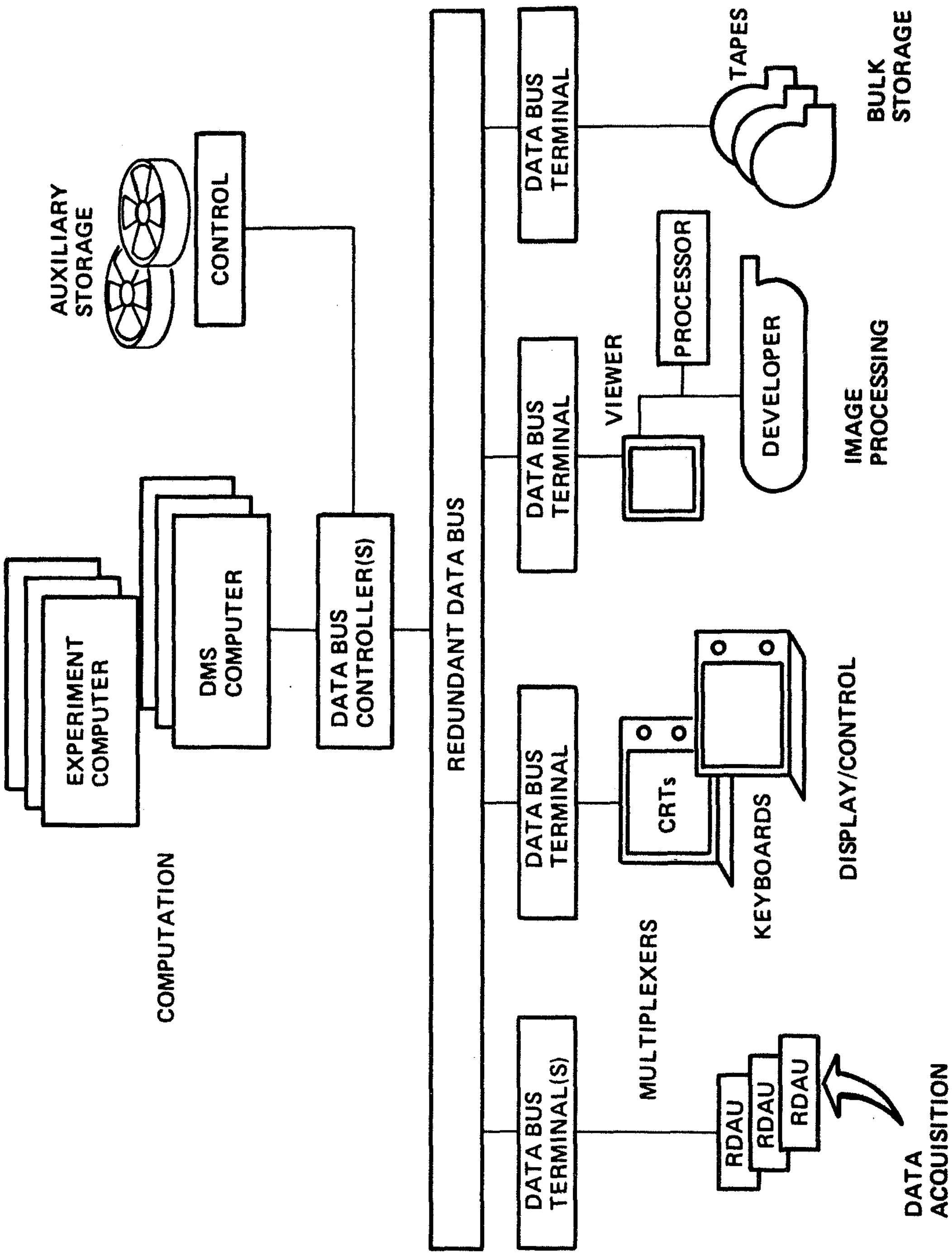

Figure 3-2. Data Management Subsystem Baseline

The DMS Computer Subsystem is comprised of:

- One - Space Station Operations Multiprocessor (3 CPUs)
- One - Space Station Experiment Multiprocessor (3 CPUs)
- Shared Main and Auxiliary Memories
- Bulk Data Storage
- Switching Matrices

Figure 3-3 depicts a functional block diagram for the Computer Subsystem. A lower level functional diagram of the individual Computer Subsystem components is given in Figure 3-4.

The six processors (CPUs) are identical in size and architecture and can provide a backup capability for one another. The main memory (256 K words) and the auxiliary memory (2.5 M words) are shared between all the CPUs and can be individually addressed through the memory switch matrix, by any of the six CPUs. These memories will be primarily used for the storage of subroutines and data that require rapid access from the CPUs. In addition, these memories can be addressed directly from the data bus for direct storage of uplinked program modifications and acquired data. The main memories are high speed monolithic memory units and the auxiliary memories are a combination of high speed magnetic tape, incremental tape, and magnetic disc units.

The bulk data storage uses ultra high density magnetic tape recorders and is configured to meet large data volume storage requirements with a relatively slow access speed. Its use is primarily for recording digital data before onboard processing or before return to earth for ground processing. As such, it will be the last level of memory in the Processing Subsystem and will store infrequently used information not requiring rapid access, such as maintenance procedures, spare parts inventories, or information that may be stored off line. The bulk data storage consists of the following elements:

- Tape Transports
- Tape Transport Controllers
- Digital Buffer and Control Unit
- Record/Reproduce Electronics
- Switching Matrices

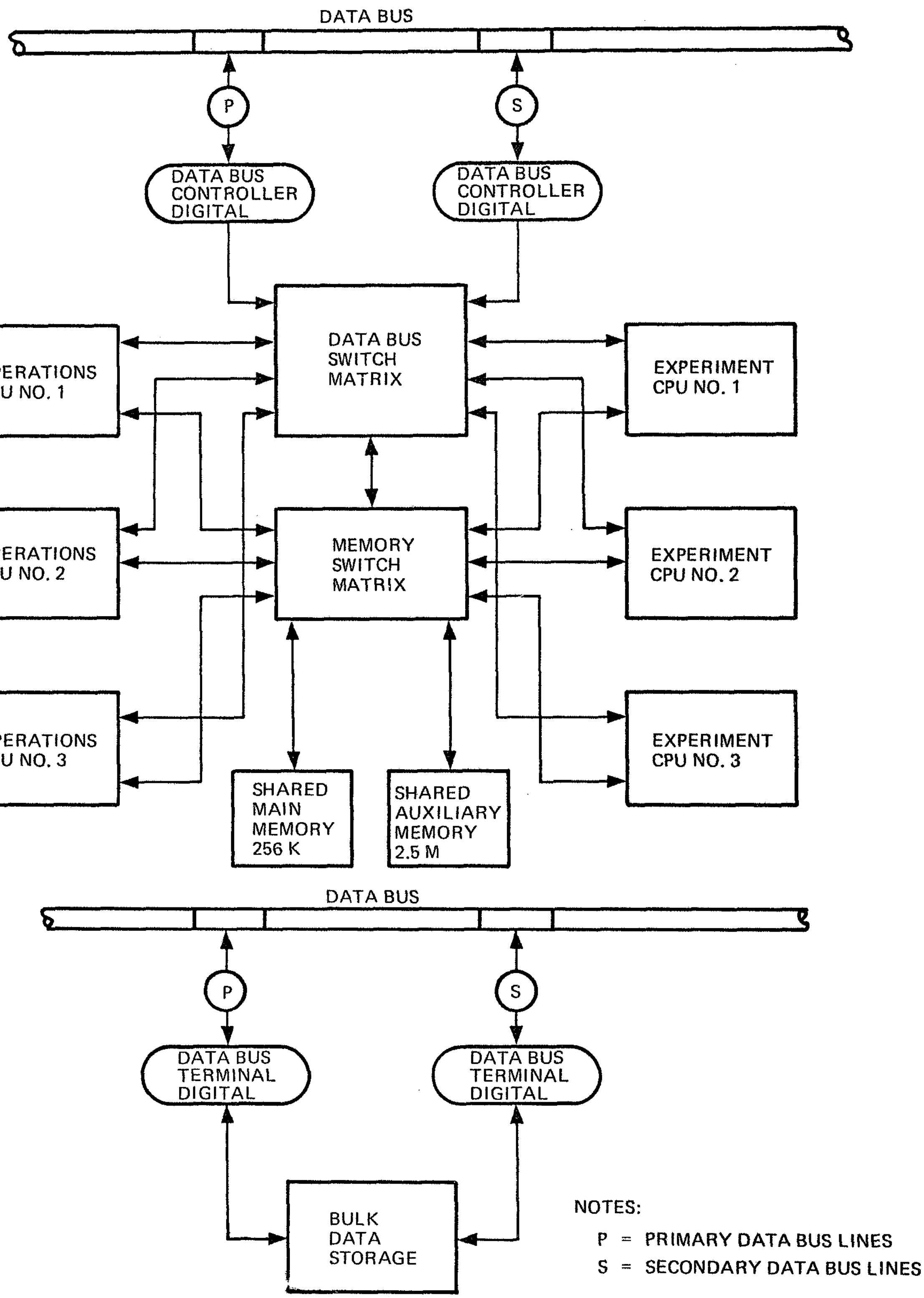

Figure 3-3. DMS Computer Subsystem

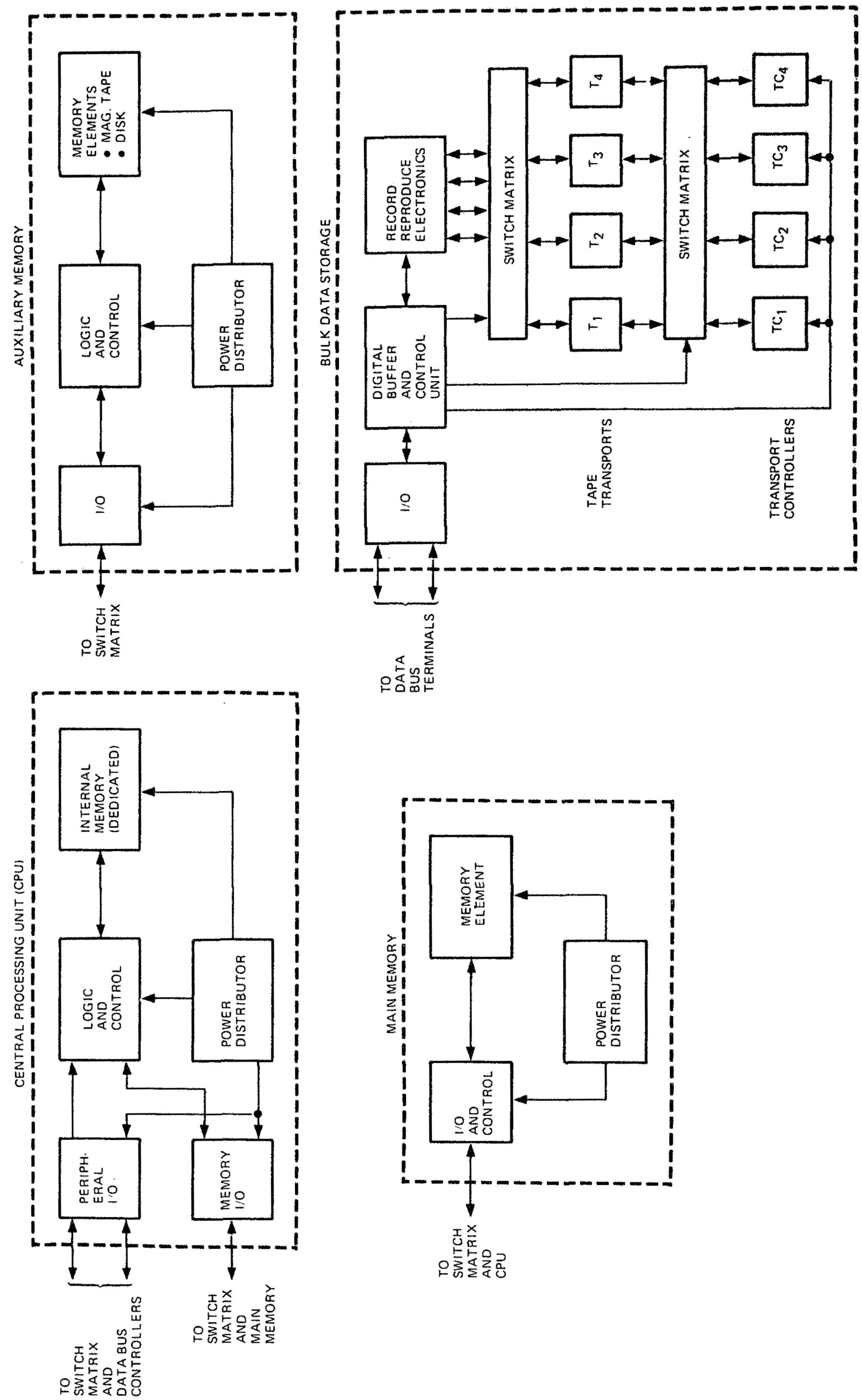

Figure 3-4. Computer Subsystem Components Functional Block Diagrams

The Data Acquisition and Distribution Subsystem is comprised of the following elements:

- Data Bus
- Digital Data Bus Terminals
- Remote Data Acquisition Units
- Local Monitor and Display Units (LMDU)

This subsystem is used by the DMS to distribute all necessary commands and acquire all required data or command responses for Space Station operation, experiment control/monitoring, and for all OCS functions. Additionally, the data bus is used for the distribution of all intercommunication and entertainment audio and video signals.

The data bus consists of redundant coaxial command and response lines (4 total) linking together all primary elements of the DMS. A total data rate greater than 50 megabits per second should be considered for this application. Twisted wire pairs or other suitable transmission lines are used for secondary data distribution common to individual data bus terminals and transmission of warning alarm signals to and from LMDUs.

The digital data bus terminals are configured for modularity and interface commonality. This terminal is designed to handle eight standard four-wire interfaces each with individual bit rates of 1 MHz or less. Each interface is isolated to prevent propagating a data source failure to another interface. A switchable modem is used as the data bus interface. The switching feature permits the modem to interchange its command and response lines such that an off-line data dump to a selected subsystem (i.e., bulk data storage) can be effected with the stated data bus configuration (i.e., separate command and response lines). Clock logic is modular and divides the data bus clock to the frequencies required by the subsystem/experiment interfaces. Buffer storage is also modular and may be provided for any or all inputs individually. This feature allows storage to be tailored to a particular interface data rate. The DMS control would efficiently utilize this storage by (1) sending a control word to cause the terminal to sample its inputs, and at a later time (2) sending a control word to request a data dump. An additional interface is provided to address the stimuli generators and other required discrete signal outputs. The terminal would be used, via a DMS control word, to energize a particular stimuli generator channel, or provide a control function (discrete signal) output. A self-check feature is provided to allow OCS fault isolation to a particular unit.

The Remote Data Acquisition Unit can be considered as a subsystem/experiment preprocessor and is designed to interface directly with the digital data bus terminal. The RDAU performs five functions on analog and digital signals. These are: signal conditioning, multiplexing, A/D conversion (analog only), limit checking, and digitizing to format the data into the standard digital format for transmission to the data bus. Signal conditioning is accomplished through a programmable gain amplifier or both programmable gain amplifier and a preconditioning (ahead of the multiplexer) network. The RDAU inputs may be discrete (on-off) or analog signals, but must be preconditioned to the proper working voltage prior to multiplexing. The A/D converter output is digitally compared with high and low limits extracted from a self-contained read/write memory. If the measured parameter exceeds either limit, the return data is flagged so the DMS processor is aware of any failures or out-of-tolerance conditions. The limits can be changed and adjusted to changing operational conditions by appropriate commands from the DMS/OCS processors.

Operation of the RDAU is under direct control of the DMS processor which transmits control information via the data bus using a standard word format containing the address of the RDAU and the appropriate instruction codes. Three operating modes are provided as described below.

- Compare Mode - The device sequentially scans the input channels and compares the digitized measurements with upper and low limits stored in the device memory. No action is taken unless an out-of-limit condition is detected, in which case an error message is formatted for transmission to the DMS processor. The stored limit values may be changed at any time under processor control. Individual channels may also be inhibited from generating error messages. These capabilities allow the limit check profile of each RDAU to be adjusted to accommodate changing operating modes or conditions of the equipment.

- Sequential Output - The device sequentially scans the input channels and transmits the digitized measurements to the processor. Limit checking is inhibited.

- Single Channel Output - The device selects a single input channel whose address is specified in the control word and transmits the digitized value to the processor. The channel may be sampled once or repetitively. Limit checking is inhibited.

RDAU inputs may be either discrete (on-off) or analog signals, but must be preconditioned to a specified voltage range. The baseline configuration accepts discrete inputs of 0 or 5 Vdc and analog inputs in four ranges of 0-20 mV, 0-50 mV, 0-100 mV, and 0-5V. Other voltage levels may be accommodated if required, at the expense of additional signal conditioning circuitry in the device. It should be pointed out, however, that the ability to accommodate the development and evolutionary growth expected to occur in the Space Station dictates the necessity to establish standard interface specifications which do not impose unreasonable constraints on either the Data Acquisition System or the data sources. Preconditioning of data at the source satisfies this requirement by providing an easily definable interface which is compatible with established instrumentation practices. The RDAU basic configuration is a device with 32 analog and 32 discrete channels. Other configurations of varied capability are also provided to attain an optimum distribution. The RDAU contains a self-test capability to allow fault isolation to the replaceable unit. A possible self-test concept is to provide calibration voltages, divided from the RDAU power input, into the input of the multiplexer. This would give an indication as to the operational status of the unit.

The LMDU, shown in Figure 3-5, is primarily an RDAU with local critical parameter display capability. It accepts both caution and warning functions and contains the necessary circuitry to: (1) monitor these critical functions continuously for out-of-tolerance conditions, (2) cause immediate activation of self-contained and external alarm indications, and (3) acquire caution and warning function data for normal checkout operations. Limit checking of critical function inputs is performed using the same methods and circuitry employed by the RDAU. Unlike the RDAU, however, the LMDU activates local alarms which are directly wired to the monitor circuitry. Transmission of critical function data to the central caution and warning displays is on the DMS data bus. In contrast to caution parameter limits, which can be changed by remote control, the stored limits for warning parameters are adjustable only by local manual replacement of individual memory modules. Detection of out-of-limit warning function activates audio and visual alarms located within the unit and, under CPU control, those located external to the unit. These include alarms in the Space Station's primary and secondary control centers, and as required in other LMDUs. Once initiated, caution and warning alarms remain active until reset. A capability is provided for selectively inhibiting individual functions to accommodate changing operational conditions. All critical functions are also redundantly monitored via the normal DMS/OCS.

The Space Station caution and warning function is considered a part of the OCS, but is implemented as a separate and redundant system for reliability. Critical measurements are monitored and out-of-tolerance indications are provided primarily through the use of Local Monitor and Display Units. Warning functions are those which, if out of tolerance, could present an immediate threat to crew life. Caution functions are those which, if out of tolerance, could result in major degradation of Space Station performance unless specific crew action is taken.

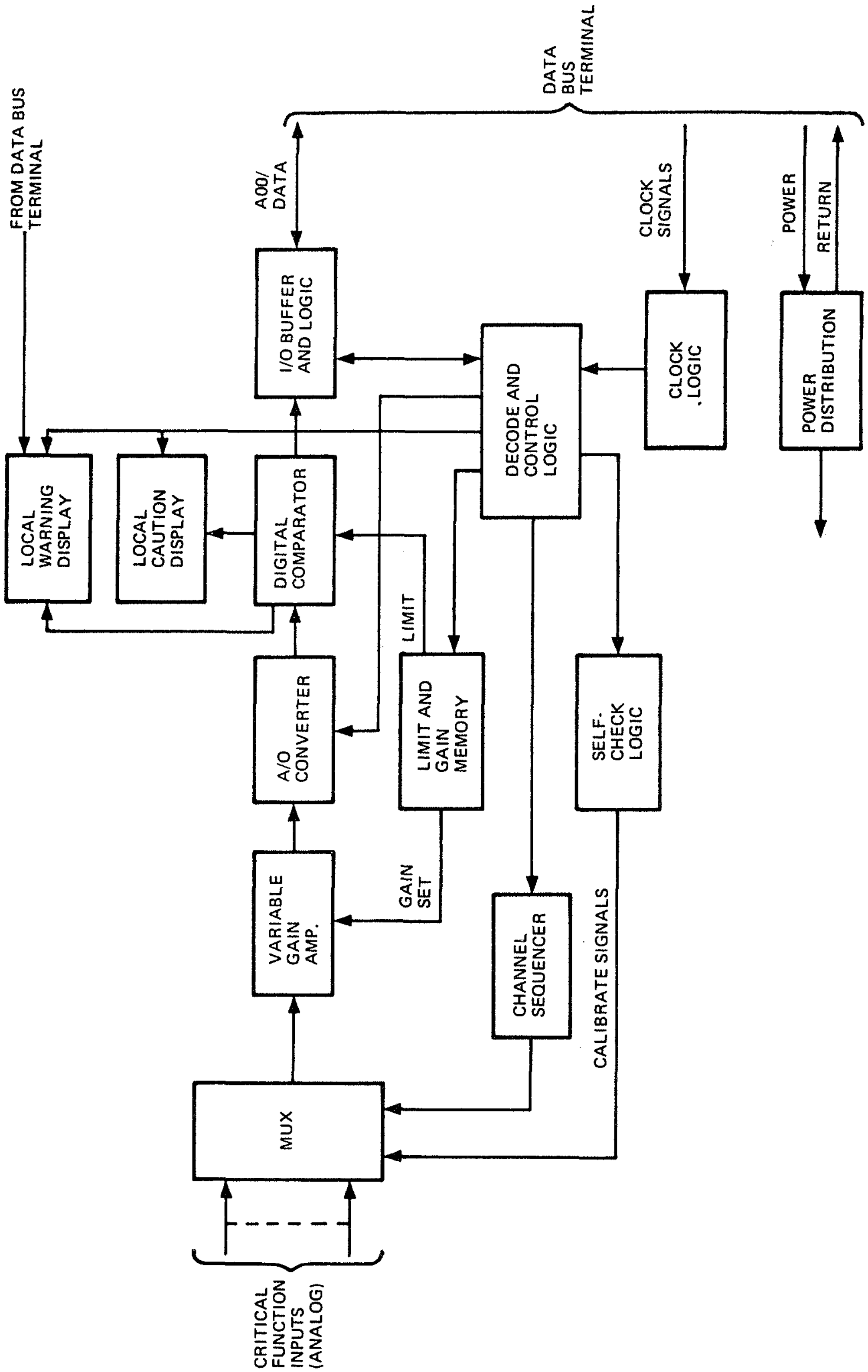

Figure 3-5. LMDU Block Diagram

A functional block diagram of the caution and warning function is shown in Figure 3-6. The redundancy of the monitoring elements can easily be seen from this diagram. Detection of an out-of-tolerance condition causes the activiation of both visual and audible alarms to notify the crew. Annunciator panels and LMDUs with appropriate displays are located in each crew compartment, where required, and on the central command and control consoles. The displays are coded (by color, tone, etc.) to differentiate between the caution and warning levels of alarm. A manual override is provided for the audible alarm.

The Image Processing Subsystem, as shown in Figure 3-7, provides onboard capability to:

- Provide quick look at experiment results
- Calibrate/align experiment instruments
- Monitor and control experiments

The Image Processing Subsystem is configured to process 1923 images per 8 hours, image content 2.5×10^6 bits each. The digital computer associated with this subsystem has tentatively been defined as the DMS Experiment Multiprocessor and is intended to be used for statistical evaluation of image data as well as derivation of annotation information. Requirements for Fourier transformations and convolution processing, in respect to additional special purpose digital processing equipment, are being analyzed.

An experimenter's station is provided which consists of an experimenter's console and display. The console communicates with the experiments it controls and with the computer and analog processor (adjustable multichannel filter). Each station display will have two CRTs for comparing images driven by the working video storage or by the computer.

The central element of the system is the Experimenter's Console which contains displays for film and image information generated in analog form. The functions controlled from the console include:

- Adjustment of viewing instruments
- Annotations and editing functions for stored, processed, and transmitted image information
- Control of processing functions in an interactive manner

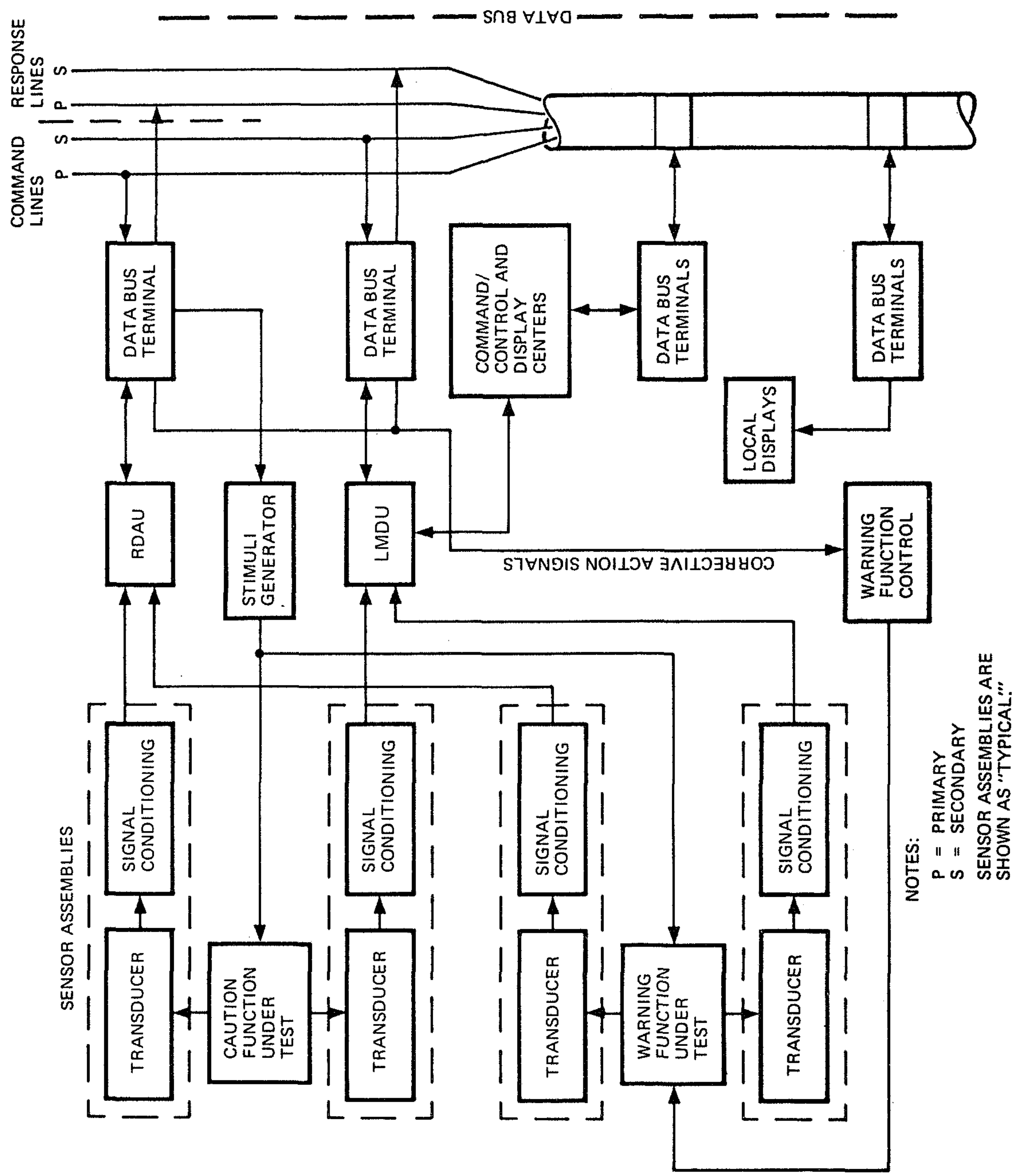

Figure 3-6. DMS/OCS Caution and Warning Functions

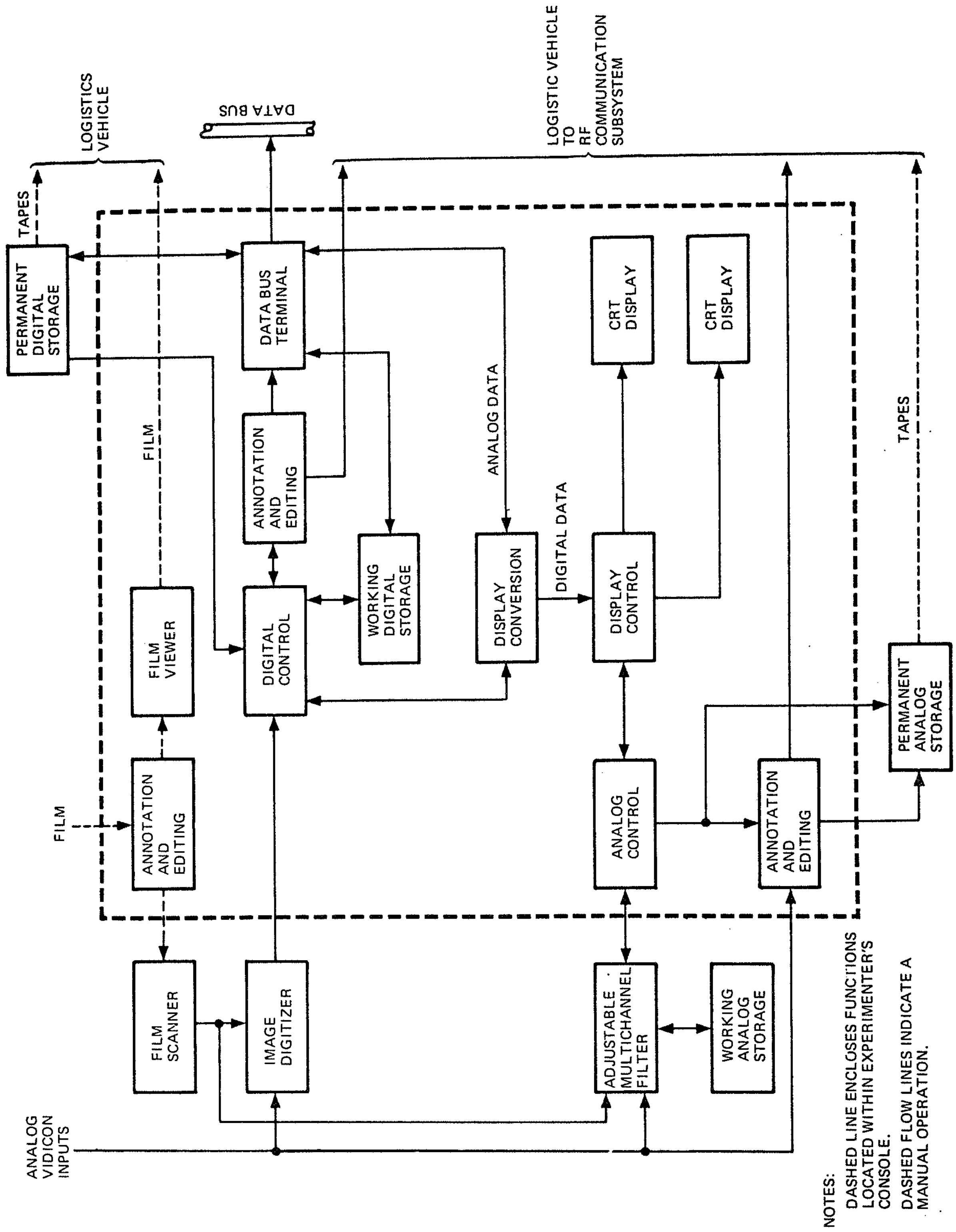

Figure 3-7. Image Processing Subsystem Functional Block Diagram

Film may be directly viewed using the film viewer/reader: This device, which provides for single-and multiple-frame analysis, consists of a screen for viewing or scanning, controls for image magnification and rotation, and a frame counter.

The film scanner is employed to transform film images into an electrical signal. For this purpose, the unit employs a high resolution flying spot scanner which may be programmed to vary the electronic sweeps and scans of the unit in order to reduce nonlinearities or obtain data only on particular areas of interest.

The Command/Control and Display Subsystem (CCDS) is comprised of the following basic elements.

- Operations CCDS Center
- Experiment CCDS Center
- Portable Display and Control Units

These units provide the primary human interface to the DMS/OCS.

The Operations CCDS Center will be the primary central command post for Space Station operations. This station provides monitoring and control capability of all subsystem "housekeeping" activities, mission planning, and personnel/activities scheduling. This station will play a central, active role during all rendezvous and docking phases with other spacecraft and experimental modules and during ground communications for command and data transfer.

The Experiment CCDS Center is a centralized operation center for monitoring and management of the experiment program. In addition, this station is capable of providing emergency/backup vehicle and subsystem control capability in the event the crew is forced to evacuate the Primary Command and Control Center because of a major emergency condition. Because of this, the Experiment CCDS Center is located in an environmentally isolatable compartment.

Displays and controls required at the experiment/Secondary Command and Control Center are basically the same as those required by the primary center, in addition to dedicated experiment displays and controls to permit complete monitoring and control capability over the experiment program.

In addition to the primary and backup control centers, a number of small portable devices are provided which contain alphanumeric displays and input keyboards. These devices may be plugged into the data bus at various locations throughout the Space Station and thereby provide an operator with limited control and display capability from remote locations. An example of their use would be in certain fault isolation situations where the operator finds it advantageous to operate from a position adjacent to the equipment under test rather than from the center location.

The command/control and display stations, Figure 3-8, contain three multipurpose CRT display devices (one primarily allocated to OCS functions) and two keyboards which provide backup redundancy. This dual design allows onboard checkout to be accomplished from this station by a second crew member on a noninterference basis while sharing common displays, readouts, status lights, etc., if necessary. Some special OCS peculiar displays such as status indicators, as well as special purpose OCS controls such as mode and function switches, are integrated into the console in such a way as to permit access by the OCS operator without interference with other console operations. The prime interface for displays and controls to the Space Station is through the DMS multiprocessor computer via the data bus. The prime control/display devices providing the interface with the computer are mode select switches, computer keyboard unit, and multipurpose CRT displays. The keyboard and associated mode select pushbutton switches provide access to and control of nonprogrammed computer operations and the CRT displays computer-generated alphanumeric/graphic information and stored/processed data. A secondary "hardwire" interface is provided for those functions, such as local controls and dedicated displays, which are wired directly and do not require transmission via the data bus. Intercom and Command Control Television (CCTV) control is provided by the Command/Control and Display Console (CCDC) via analog interface units.

The GN&C preprocessors are included within the DMS only to the extent of their interconnection with the data bus through required data bus terminals. Five preprocessors and associated data bus terminals have been configured for the GN&C Subsystem. These preprocessors provide the capability of operationally interfacing the individual GN&C sensors and controls via required interface electronic assemblies to the operations multiprocessor. In addition, it is anticipated that a significant amount of data formatting and "housekeeping" computations will be accomplished by these preprocessors, thereby relieving the overall operations multiprocessor load. Specific assignments of data formatting and computation to the individual GN&C preprocessors have yet to be determined.

It is assumed that the preprocessors will be simplex, dedicated digital computers with a self-test capability. Specific signal conditioning for inputs and outputs to the GN&C sensors and controls will be accomplished by the interface electronics assemblies, a part of the Guidance, Navigation, and Control System. The preprocessor-to-data-bus interface will be through a standard data bus terminal.

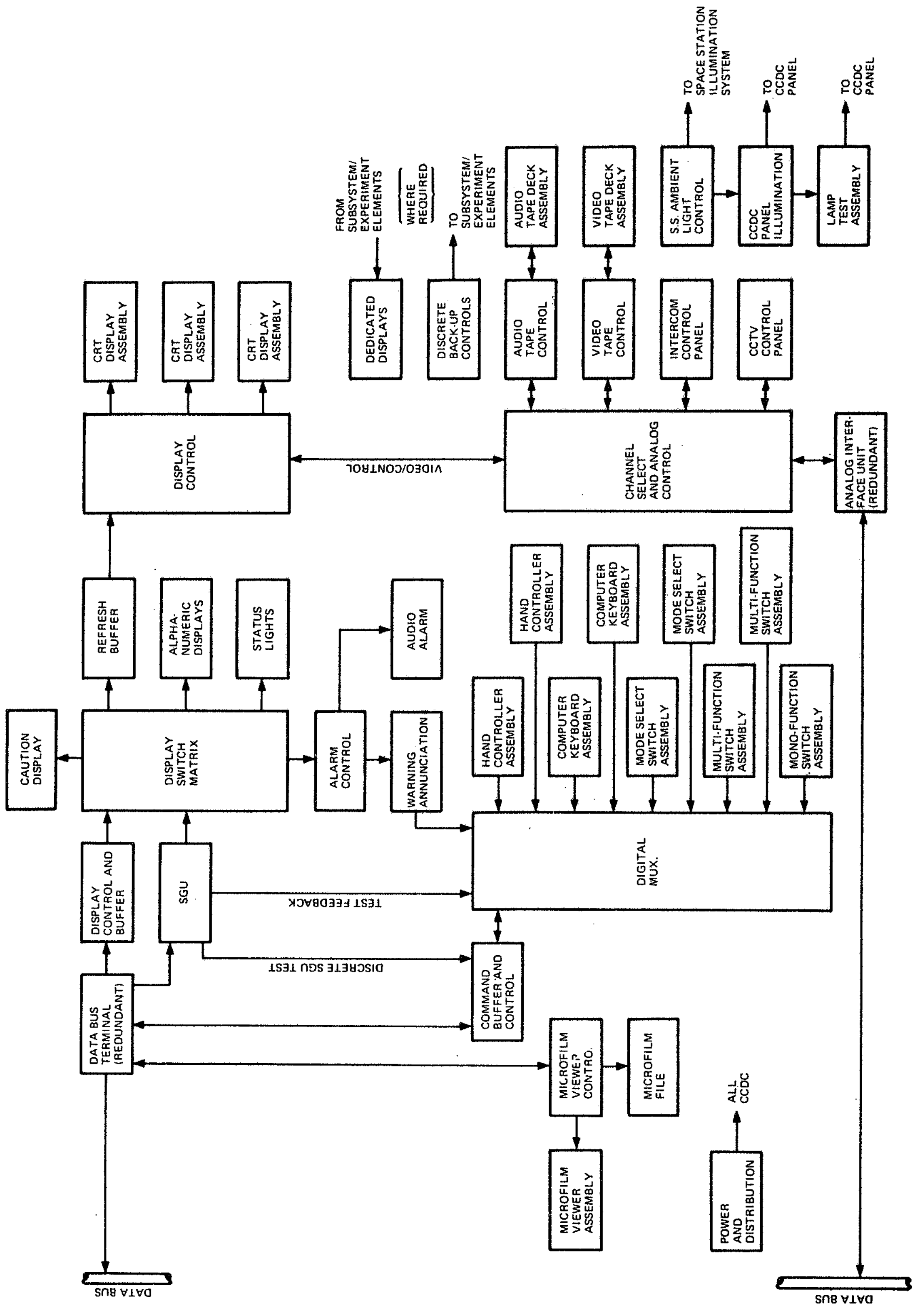

Figure 3-8. Command/Control and Display Console Functional Block Diagram

3.7.2 ASSEMBLY LEVEL DESCRIPTIONS

Subsystem block diagrams and descriptions of the Data Management Subsystem assemblies not included here are provided in the Space Station MSFC-DRL-160, Line Item 13, Volume I, Book 2, Space Station Electronics. These descriptions include block diagrams, discussion of major subassemblies, physical characteristics, and interface descriptions. DRL 13, Volume I, Book 2, is incorporated by reference into this report as a detailed description of the DMS assemblies and, except where modified by this document, will become the primary working document for further analysis.

3.8 STRUCTURE SUBSYSTEM

3.8.1 SUBSYSTEM LEVEL DESCRIPTION

The Space Station structure consists primarily of four subsystem areas which will require checkout support. They are:

- Basic Structure
- Docking Mechanisms
- Spacecraft Access
  - Hatches
  - Airlocks
  - View Ports
- Antenna Deployment Mechanisms

3.8.1.1 Structure

The basic Space Station structure provides the necessary pressurized habitat, equipment support, meteoroid protection, radiators, insulation, and docking interfaces. Attainment of the required volume for the accommodation of crew, experiments, and subsystems within a 110, 000-pound weight limit demands that the structure design be optimized. The structure must also have adequate factors of safety to satisfy the long life (ten years) requirements. The design uses state-of-the-art materials, design, and fabrication techniques.

The external cylindrical pressure shell and the center tunnel structure are 2219 aluminum alloy with integrally machined waffle stiffeners on the external shell and integral stabilizing rings on the tunnel. Each two-deck module is closed at each end with a toroidal dome membrane. The equipment in each module is supported by the deck structure located halfway between the domes. The deck is formed by a radial array of beams extending from the center tunnel to the external pressure shell. The thrust loads in the center tunnel structure are carried to the external pressure shell structure through a conic structure at the forward end of the station.

ECS radiator, thermal insulation, meteoroid protection, and a pressure shell are integrated into a 4.5 inch thick sandwich design. The external surface of 0.020-inch beaded aluminum sheet serves the dual function of being both the primary meteoroid bumper and the radiating surface for the ECS radiator. An inner, 0.010-inch corrugated aluminum sheet provides additional meteoroid protection and limits insulation blanket damage over the 10-year life. The two bumpers are supported by 1 section aluminum extrusions which contain dual passages for the ECS radiator fluid. The 0.110-inch, waffle stiffened pressure shell forms the interior surface of the sandwich. Tests of this design at the MDAC light gas gun facility have indicated that the no meteoroid puncture probability of the pressure shell is 0.985 for ten years.

3.8.1.2 Docking Mechanism

The docking mechanism accomplishes the physical alignment of the vehicles, attenuates the relative closing velocities, and captures and rigidizes the two vehicles. In addition to the mating of the two vehicles, the system must accomplish the disconnection, detachment, and separation of the spacecraft from the Space Station.

The conceptual design prepared for the docking mechanism and shock absorber/actuator is described as follows. A gas spring is used for energy absorption so that the pressure can be varied to accommodate wide variations in the masses of the vehicles to be docked. A floating piston separates the gas from a low temperature hydraulic fluid. As the shock absorber strokes, the hydraulic fluid flows through a one-way valve and drives the floating piston down the shock absorber, doing work against the gas pressure. When the compression stroke is completed, the one-way valve prevents the shock absorber from springing back. A small bypass orifice permits it to return at a slow, controlled rate to its initial extended length. The gas spring pressure can then be reduced for retracting the frame to the stowed position.

3.8.1.3 Access Hatches, Airlocks, View Ports

In the evolution of the Space Station configuration, the requirement for crew access to the various compartments, docked modules, external portions of the station, and consideration of redundant transfer paths in case of emergencies is essential for crew safety considerations. While normal crew activities and access to experiment and cargo modules will be accomplished in a shirtsleeve environment, some contingency operations will require pressure suit and airlock transfer capabilities.

The requirement for two separately pressurized volumes has been provided by the two-deck, common module design approach; in addition, the 10-foot-diameter center tunnel provides a third pressure volume. The expendables compartment is normally unpressurized except for shirtsleeve access for maintenance and repair. The forward portion of the center tunnel can be used as an airlock if necessary.

Each deck will have a 5-foot-diameter clear opening access hatch into the tunnel. These hatches will be open for the normal traffic flow, but, in cases of emergency, may be closed and sealed against fire, contamination, or depressurization in one of the common modules. If one of the common modules is depressurized, the tunnel environment will be referenced to the other common module environmental control system. Using pressure suits, the crew may then reenter the depressurized module for inspection and repair through the fixed airlock. This airlock will also permit access to the outside of the Space Station from either of the common modules for normal EVA activities.

3.8.1.4 Antenna Deployment Mechanism

The Space Station requires four 15-foot diameter communications antennas to provide high-gain RF acquisition and continuous tracking of relay satellites. These antennas are stowed during launch under the nose fairing together with the artificial-g telescoping spoke. Upon reaching orbit and ejection of fairings, the antenna mounting booms shall be extended and locked in operating position until artificial gravity operation. The antenna mounting boom requires the capability of being retracted and locked in a low inertia position during the artificial gravity mode. The antenna shall have a two-axis gimbal positioner located at the antenna end of the mounting boom. The azimuth axis shall be parallel to the Space Station Z axis. Each antenna shall be capable of scanning 360 degrees in azimuth and from +75 degrees to -10 degrees in elevation. During maintenance, the antennas shall be retracted to air lock ports where the back side of the antenna is accessible to intervehicular astronauts. The antenna locations shall be 45 degrees off the major Y-Z axes. The antenna masts are fixed length and actuated by an electric motor drive train located at the hinge line. Flexible power and signal leads must be provided at the hinge to provide power to the antenna drive and to transmit position signals. In addition, a swivel type waveguide must be provided at the mast hinge line.

3.8.2 ASSEMBLY LEVEL DESCRIPTIONS

Space Station MSFC-DRL-160, Line Item 8, Volume V, Book Mechanical, contains a description of the mechanical subsystem elements sufficiently detailed for checkout requirements analysis purposes and will become the primary working document for this purpose. MSFC-DRL-160, Line Item 8, Volume V, Book 6, is incorporated into this report by reference.

Section 4

RELIABILITY AND MAINTAINABILITY ANALYSES

4.1 CRITICALITY ANALYSIS

As a guide to emphasis in subsequent checkout technique studies, an analysis has been made of the overall subsystem and major component criticality (failure probability) of the Space Station subsystems and equipment. As an input to the Checkout Requirements Analysis Task, this data along with the failure mode and effects data will be useful in determining test priorities and test scheduling. Additionally, this data will aid in optimizing checkout system design to ensure that confidence of failure detection is increased in proportion to added system complexity and cost.

4.1.1 CRITICALITY ANALYSIS PROCEDURE

A criticality number (failure probability) was generated for each major subsystem component. This number is the product of: (1) the component failure rate (or the reciprocal of mean-time-between-failure), (2) the component's anticipated usage or duty cycle, and (3) an orbital time period of six months, or 4,380 hours. Six months was chosen as the time period of interest to allow one missed resupply on the basis of normal resupply occurring at three-month intervals. The criticality number, then, is the failure expectation for a particular component over any six-month time period.

For visibility, the major components of each subsystem analyzed have been ordered according to the magnitude of their criticality numbers. This number, however, should not be considered as an indication of the real risk involved, since it does not take into account such factors as redundant components, subsystem maintainability, and the alternate operational procedures available.

Overall subsystem criticality has been determined by a computerized optimization process whereby spares and redundancy are considered in terms of a trade-off between increased reliability and weight. This determination, therefore, reflects not only the failure probability of subsystem components, but also the probability that a spare or redundant component may not be available to restore the subsystem to operational status. The methodology used is described in Section 9, Long-Life Assurance Study Results, DRL 13 (Preliminary Subsystem Design Data), Volume III (Supporting Analyses), Book 4 (Safety/Long Life/Test Philosophy) from the MDAC Phase B Space Station Study. Component-level failure mode and criticality data are presented in subsequent paragraphs.

4.1.2 SUBSYSTEM CRITICALITY DATA

4.1.2.1 Guidance, Navigation, and Control

The Guidance, Navigation, and Control (GN&C) Subsystem has a six-month reliability of 0.998 and requires 1,000 pounds of spares for its achievement. An ordered ranking of GN&C component criticality is provided in Table 4-1.

4.1.2.2 Propulsion

The Propulsion Subsystem six-month reliability prediction with 600 pounds of spares is 0.992. The two independent low thrust systems with inherent replacement capability of many critical components provide a high degree of assurance that orbit-keeping functions will be sustained for a ten-year period. No single or credible combination of failures can cause loss of the Propulsion System.

The criticality ranking of Table 4-2 indicates that the two-stage CO_2 and CH_4 pumps are the most critical. An additional spare unit may qualify here and greatly reduce the overall risk of failure.

4.1.2.3 Environmental Control and Life Support

The Environmental Control and Life Support Subsystem (EC/LS) has a six-month reliability of 0.997 and requires 1,780 pounds of spares for its achievement. An ordered ranking of EC/LS component criticality is provided in Table 4-3.

Two completely independent EC/LS subsystems exist onboard the Space Station, either of which is capable of supporting the crewmen for extended periods of time. Table 4-3 ranks EC/LS components in an artificial worst case environment reflecting nonexistence of any backup system, but also provides conditional criticalities assuming the availability to both the backup subsystem and spares.

4.1.2.4 RF Communications

The optimized six-month reliability prediction for the Communications Subsystem is 0.9972 with 562 pounds of spares. This value assumes optimum performance of all components with no alternate paths of reception and transmission allowed. This value cannot be obtained directly from the criticality numerics given in Table 4-4.

Loss of digital data transmission to ground via relay satellite would require either communicating directly with the ground until the failed component was replaced, or storing digital data for transmission at a later time. This concept is reflected in the "conditional loss criticality" column of Table 4-4.

Table 4-1. Guidance, Navigation, and Control Criticality Ranking

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
Attitude Gyro Assembly	87,600	760	Considers backup for each of 3 gyros
Sensor Interface Electronics	72,000	500	Estimate based on internal redundancy and backup unit
Star Sensor Assembly	50,000	300	Considers horizon sensor assembly as degraded backup means of S/S reference
CMG Electronics	44,000	50	Includes risk that nonoperating electronics has failed
Star Tracker Assembly	41,800	72	Considers one operating and one nonoperating backup
Control Moment Gyro	21,900	<100	Two nonoperating CMGs
Landmark Tracker Assembly	8,800	8	Includes risk that nonoperating backup is failed
Alignment Monitoring System	8,800	<10	Considers backup spares failure risk
Low-g Accelerometer	8,780	8	Considers failure of nonoperating backup
Horizon Detector	7,200	50	Either detector can provide course attitude info during artificial-g

Table 4-1. Guidance, Navigation, and Control Criticality Ranking (Continued)

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
Horizon Sensor Assembly	6,300	300	Considers star sensor as alternate means of reference
Laser Rendezvous Tracker	4,400	<10	Two nonoperating backups exist
Reaction Jet Driver Electronics	3,070	1	Backup spare risk
Laser Docking Tracker	2,200	<10	If one laser docking tracker fails, docking can be accomplished at another docking port

Table 4-2. Propulsion Subsystem Criticality Ranking

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
Pump and Motor	166,000	9,500	This numeric applies to both CO_2 and CH_4 pumps. Considers backup 2-stage pumps as nonoperating until required
Power Control Assembly	43,800	20	Internal redundancy plus backup
GN_2 Purge Tanks	42,000	180	Backup N_2 aboard S/S
Propellant Tank Assembly	42,000	2,000	Operation allowed with 11 of 14 tanks
Thruster Modules	13,700	75	Considers backup for despin and docking disturbance
Regulators	12,300	144	Applies to CO_2 and CH_4 regulators w/backup
Pressure Regulator (GN_2)	12,300	144	Backup failure considered
Relief Valves	8,900	16	Considers risk of GN_2 tank overpressurization
Burst and Relief Valve	8,900	56	Considers risk of propellant tank overpressurization

Table 4-2. Propulsion Subsystem Criticality Ranking (Continued)

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
H_2O Tank	5,900	<10	Backup tank plus alternate source of CH_4 and CO_2 available
Accumulator (CH_4)	5,900	<10	Backup accumulator plus CH_4 can be obtained directly from EC/LS
Accumulator (CO_2)	5,900	<10	Backup accumulator plus CO_2 can be obtained from EC/LS
Valve Solenoid CO_2 Line to Accumulator	3,160	1	Backup plus EC/LS furnished CO_2 available
Valve Solenoid CH_4 Line to Accumulator	3,160	1	Backup plus EC/LS furnished CH_4 available
Regulation Valves	3,160	<10	Backup exists
Cross Feed Valves	3,160	<10	Backup exists
Isolation Valves	3,160	<10	Backup failure considered
Isolation Valves	3,160	<10	Backup failure considered
Valve, Solenoid (H_2O Tank to Vaporizer)	2,960	<10	Backup failure considered

Table 4-2. Propulsion Subsystem Criticality Ranking (Continued)

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
Water Vaporizer	1,120	<10	Backup failure considered
Manifold	1,120	<10	Backup failure considered
Thruster Assembly	700	<10	Backup failure considered
Tank, Storage GN_2 (3000 psia)	440	<10	Backup failure considered
Pressure Switch Hi/Low	220	<10	Backup failure considered
Burst Disk	150	<10	Backup failure considered
Water Tank Heater	88	<10	Backup failure considered
Filter	44	<10	Backup failure considered
Filter	44	<10	Backup failure considered
Fluid Resupply Connectors	Neg'l		

Table 4-3. EC/LS Criticality Ranking (Highest 25 Components)

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
2590 Electrolysis Module	675,000	150 includes 6 spares	
6304 Pump/Motor	146,000	73	
6604 Pump/Motor	146,000	73	
6104 Pump/Motor	146,000	73	
2341 CO_2 Compressor	86,000	750	
1302 Pressure Control	83,000	100	
2231 Fan	47,500	100 (for 2231, 2242, 2241, 2140, 2340, 2642 Fans)	
2242 Fan	47,500		
2241 Fan	47,500		
2140 Fan	47,500		
2340 Fan	47,500		
2642 Fan	47,500		

Table 4-3. EC/LS Criticality Ranking (Highest 25 Components) (Continued)

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
2370 Valve, Sequence Controller	43,800	10	
2302 CO_2 Diverter Valve	43,800	10	
2304 Silica Gel Diverter Valve	43,800	10	
3205 Mal Sieve Diverter Valve	43,800	10	
3370 Control	43,600	10	
3314 Valve, Temp Control	40,000	7	
2141 Water Pump	37,000	105	
3340 Pump	37,000	105	
2440 Condensate Pump	36,800	105	
2571 Current Controller	32,000	44	
1805 Rotating Compressor	26,200	200	

Table 4-4. Communications Subsystem Criticality Ranking - Highest 10

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
S-Band PM Transponder	41,800	450	Reflects that ground transmission via DRSS is inoperative
K_u-Band Power Amplifier	31,400	<100	Reflects ground direct transmission inoperative
FM Xmtr Modem	18,400	970	Reflects that direct ground communication is inoperative
High-Gain Antenna System Assembly	12,500	1290	Reflects less than optimum antenna positioning
S-Band Video Receiver Modem	11,400	<100	Considers 3 spares not operating
S-Band Power Amplifier	9,000	<100	Considers ground communication via DRSS outage
S-Band FM Exciter	7,100	128	Considers backup with ground communications via DRSS
S-Band Data Receiver	5,030	<100	Considers 3 spares available
S-Band Video Receiver	4,600	<10	Spares available
S-Band PM Receiver	3,420	<10	Spares available

4.1.2.5 Structures

Reliability for the Structural and Mechanical Subsystem for six months is 0.995 and requires 75 pounds of seals and meteoroid patches to achieve. This equates to a subsystem criticality numeric of 5×10^{-3} for each six-month orbital interval. This value implies that there is a 0.5 percent risk that adequate spares will not be available when required or that a puncture in the pressure shell will occur that cannot be repaired. Component-level criticality numbers in Table 4-5 were estimated directly since conventional mean-time-between-failure numerics are not appropriate for structural components.

4.1.2.6 Electrical Power

The optimized six-month reliability for the Electrical Power Subsystem (EPS) is 0.997 and requires 1,300 pounds of spares for its achievement. An ordered ranking of EPS component criticality is provided in Table 4-6.

4.1.2.7 Data Management Subsystem

The Data Management Subsystem has a six-month reliability of 0.998. This figure is based upon the currently projected potential reliabilities of the components (some of which are in the early development stage),critical failure definitions based upon preliminary DMS functional definitions, and adequate sparing. Criticality numbers for units which are internally redundant cannot be established at this time since the actual values will depend upon detail design. No single failure or credible combination of failures can cause loss of the major DMS functions. Table 4-7 provides the ordered ranking of DMS components.

4.2 FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

A preliminary FMEA was performed under Task 1 to allow work to proceed on subsequent subtasks of the Requirements Analysis and Concepts Task. However, resources available under Task 1 did not allow the analysis to be completed to the depth desired. Redirection of Task 5, "Reliability," has released additional funds to increase the depth of this analysis. The preliminary analysis completed under Task 1, therefore, will not be reported here. The revised and improvised FMEA will be reported under Task 5.

4.3 MAINTENANCE CONCEPT ANALYSIS

Maintenance concepts defined for Space Station subsystems are intended to facilitate their preservation or restoration to an operational state with a minimum of time, skill, and resources within the planned environment.

Table 4-5. Structures Subsystem Criticality Ranking

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
Primary Structure	1,000	500	Considers that 1/2 the risk can be negated by patching meteoroid penetrations, utilizing makeup O_2 for leakage, and stopping meteoroids with the meteoroid shield
Radiator	1,000	500	Considers that 1/2 the risk can be deleted by replacing segments and isolating leaks
View Port Seals	500	100	Leakage can be made up by emergency O_2
Tunnel Hatches	500	100	Redundant seals and more than one exit from compartment exist
Docking Ports	360	10	Considers repair of docking ports plus capability of docking at any port if one docking mechanism is damaged
Main Airlock	300	10	Replaceable seals and makeup O_2. EVA can also be accomplished via forward section
Antenna Deployment Mechanism	100	10	Provides for less than optimum coverage if one antenna is out and EVA to repair
Fairings	100	10	EVA can release

Table 4-6. Electrical Power Criticality Ranking

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
Heat Rejection System	132,000	1,750	Backup heat rejection system. Includes failure to start up, four primary and four secondary radiator loops and two are standby
1.3 kW Sine Wave Inverter	47,000	220	Standby unit on line. Internal short can be cleared. Circuit breaker trips
1.0 kW Sine Wave Inverter	47,000	<10	Same as 1.3 kW 400 H_3 inverter plus emergency inverter backup
5.8 kW Square Wave Inverter	47,000	220	Standby unit on line. Circuit breaker will trip against overload
Power Conversion Loop	45,500	500	One standby spare PCS reduces criticality to 5000. Ability to switch on batteries and/or tolerate 1/2 power should reduce criticality to 500
IRV Heat Source	16,700	40	S/S batteries pushing up load could reduce criticality as shown for up to 24 hours or until new heat source was obtained. Must resort to heat dump mode utilizing quad redundant springs, bi-redundant hinges, to reduce crew hazard
Battery Chargers	4,700	<10	Includes backup charger plus extended capability to operate without battery recharge until new charger resupplied
Regulated Hi Voltage Rectifier	2,630	25	Includes partial loss of redundancy

Table 4-6. Electrical Power Criticality Ranking (Continued)

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
5 kW Regulated X frm/Rectifier	1,800	2	For "fail open", output is sensed, failed unit isolated, and standby unit brought on line. Internal short is cleared by reverse current relay in output and circuit breaker in input
Batteries	1,100	<10	Spare battery available plus modules. Can curtail experiments requiring peak power. Batteries are double contained (sealed to prevent KOH leakage)
All Other Components		<10	

Table 4-7. DMS Criticality Ranking

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
Experiment Processor	83,870	Not Available	*2/3
Operations Processor	83,870		2/3
Main Memory	8,700		12/14
Auxiliary Memory	354,670		2/4
Digital Terminal	21,660		13/15
Remote Data Acquisition Unit	4,370		
Local Mon/Disp Unit	5,242		
Tape Transport Controller	8,700		2/4
Tape Transports	354,670		2/4
Tape Electronics Unit	21,660		1/2
Switching Matrix	--		Internally redundant

* Information based on two of three units operational.

Table 4-7. DMS Criticality Ranking (Continued)

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
Film Viewer	83,870	Not Available	
Film Scanner	196,678		
Filter	21,660		
Display/Console	196,678		
Control/Display Console	481,600		1/3
Time Reference Unit	--		Internally redundant
Printer	354,670		1/2
Command Decoder	--		Internally redundant
Remote Command Distributor	8,700		15/16

The maintenance concepts defined here shall be used as guidelines in defining Line Replaceable Units in a subsequent subtask.

4.3.1 GENERAL SPACE STATION MAINTENANCE POLICY

It is a Space Station objective that all elements be designed for a complete replacement maintenance capability unless maintainability design significantly decreases program or system reliability. This objective applies to all subsystems wherever it is reasonable to anticipate that an accident, wearout, or other failure phenomenon will significantly degrade a required function. Estimates of mean-time-between-failure, or accident/failure probability, are not accepted as prima facie evidence to eliminate a particular requirement for maintenance. Should the accident/failure probability be finite, the hardware is to be designed for replacement if it is reasonable and practical to do so.

As a design objective, no routine or planned maintenance shall require use of a pressure suit [either EVA or internal vehicular activity (IVA)] . Where manual operations in a shirtsleeve environment are impractical, remote control means of affecting such maintenance or repairs should be examined. However, EVA (or pressure suit IVA) is allowable where no other solution is reasonable, such as maintenance of external equipment.

Time dependency shall be eliminated as a factor of emergency action insofar as it is reasonable and practical to do so. This includes all program aspects of equipment, operations, and procedures which influence crew actions. When time cannot be eliminated as a factor of emergency action, a crew convenience period of 5 minutes is established as the minimum objective. The purpose of the convenience period is to provide sufficient time for deliberate, prudent, and unhurried action.

4.3.2 ONBOARD MAINTENANCE FACILITY CONCEPTS

In addition to OCS/DMS capabilities, other onboard maintenance support facilities provided on the Space Station include:

- Special tools for mission-survival contingency repairs such as soldering, metal cutting, and drilling, as determined from contingency maintenance analyses, although repairs of this type are not considered routine maintenance methods.

- Protective clothing or protective work areas for planned hazardous maintenance tasks (such as those involving fuels, etc.).

- Automated maintenance procedures and stock location data for both scheduled and unscheduled maintenance and repair activities.

- Real-time ground communication of the detailed procedures, update data, and procedures not carried onboard.

- Onboard cleanroom-type conditions by "glove box" facilities compatible with the level at which this capability is found to be required.

- Maintenance support stockrooms or stowage facilities for spares located in an area that provides for ease of inventory control and ready accessibility to docking locations or transfer passages.

4.3.3 SUBSYSTEM MAINTENANCE CONCEPTS

Space Station subsystems utilize modular concepts in design and emplacement of subsystem elements. Subsystem modularity enhances man's ability to maintain, repair, and replace elements of subsystems in orbit. Providing an effective onboard repair capability is essential in supporting the Space Station's ten-year life span since complete reliance on redundancy to achieve the long life is not feasible. The need for a repair capability, in turn, requires that a malfunction be isolated to at least its in-place remove-and-replace level. The level of fault isolation is keyed to the LRU, which is the smallest modular unit suitable for replacement. The identification of subsystem LRUs is addressed as a separate, but interdependent, part of the Onboard Checkout Study.

Specific subsystem maintenance concepts, of course, depend upon examination of the subsystems. These concepts are discussed in subsequent subparagraphs. General subsystem-related maintenance guidelines that have been established for the Space Station are:

- It is an objective to design so that EVA is not required. However, EVA may be used to accomplish maintenance/repair when no other solution is reasonable.

- Subsystems will be repaired in an in-place configuration at a level that is acceptable for safety and handling, and that can be fault-isolated and reverified by the integrated OCS/DMS. This level of maintenance is referred to as line maintenance and the module replaced to effect the repair is the LRU.

- A limited bench-level fault isolation capability will be provided on the Space Station, but is only intended for contingency (recovery of lost essential functions beyond the planned spares level) or for development purposes. Limited bench-level support is also provided in the form of standard measurement capabilities which are used primarily to reduce the amount of special test equipment required.

- Subsystem elements, wherever practical, will be replaced only at failure or wearout. Limited-life items that fail with time in a manner that can be defined by analysis and test will be allowed to operate until they have reached a predetermined level of deteriorated performance prior to replacement. Where subsystem downtimes for replacement or repair exceed desirable downtimes, the subsystem will include backup (redundant) operational capability to permit maintenance. Expendable items (filters, etc.) will be replaced on a preplanned, scheduled basis.

4.3.3.1 Guidance, Navigation, and Control (GN&C)

The GN&C assemblies will be designed for maintenance at the modular level except for the precision sensor assemblies. The sensor assemblies, in general, will be replaced as a unit because of the tight mechanical tolerances involved in the assembly packaging. The instrument gyros shall be replaceable individually from the gyro assembly; and all gyros shall be interchangeable. Onboard calibration of the gyros shall be used to define their sensitive axis alignment.

The various control and interface electronics shall be contained in standardized plug-in modules.

The control moment gyros shall be located in pressurized (or pressurizable) compartments for ready access to maintenance. CMGs shall be designed for component repair/replacement capability.

Trackers and sensors mounted externally shall be designed for retraction to permit repair and replacement in a pressurized volume (shirtsleeve). To provide access to the sensor for maintenance, the sensor mount is remotely hinged into the unpressurized sensor bay. A hatch is positioned over the opening, sealed, and the sensor bay is pressurized. Then, an access hatch is opened from the common module to allow sensor maintenance. Sensor alignment and calibration are provided by the calibration base, which is a structurally rigid element with alignment monitoring reflectors on the inside end and calibration targets on the outside end. After replacement and positioning of the sensor in its operational configuration, the alignment monitor determines the calibration base alignment. The sensor is then pointed to acquire the targets on the calibration base while the corresponding sensor outputs are read off for calibration.

The laser docking trackers shall incorporate indicators at the docking safety officer station to indicate substandard performance with regard to critical parameters subject to maintenance control.

4.3.3.2 Propulsion

The Propulsion Subsystem design incorporates specific maintenance or related provisions to satisfy the provisions of the general Space Station maintenance policy. The subsystem is designed for shirtsleeve maintenance, whenever possible, and no EVA shall be required.

Maintenance removal and replacement are by components and/or assemblies; i.e., no component adjustment and/or disassembly of components are necessary.

No scheduled maintenance (remove and replace) is planned with the exception of filters. Critical failure modes have safeguards (backup/redundancy or automatic fault isolation) designed into the subsystem.

The need for removal and replacement is determined by evaluation of:

- Leak and functional checks
- Actual life history of component and/or assemblies
- Performance checks
- Past development results/history

Safety provisions and/or procedures for normal crew maintenance operations are provided; for example,

- Propulsion subsystem assemblies are housed/installed in unpressurized (pressurizable) compartments.
- Propellant leak detection capability is provided in the compartments.
- Decontamination/cleaning methods/procedures for "breaking" into the subsystem (i.e., propellant removal from lines, components, filters, tanks, etc.) shall be established.

Reliability shall not degrade below the design reliability established. The design reliability is provided by:

- Maintenance/replacement of components and assemblies to meet design reliability requirements over a ten-year period.
- Safety factors/working stress levels that satisfy ten years of operation/fatigue, creep, corrosion, etc., wherever practical.

- More redundancy and/or automatic fault isolation for critical malfunction which affect safety of operations. The safety design feature must allow a mission operation to be completed (degraded performance allowed). This also allows maintenance to be scheduled whenever it is required.

The subsystem maintenance and operational approaches listed above will normally provide an autonomous Propulsion Subsystem with the reliability and safety needed for a ten-year mission. These features allow a balanced subsystem design approach to be taken to obtain the high reliability and safety needed without excessive redundancy/backup and the resulting complexity, volume, and weight penalties.

4.3.3.3 EC/LS

The EC/LS Subsystem represents the largest maintenance workload and the greatest potential for commonality in design for maintenance. The EC/LS Subsystem will, for the most part, be maintained at the component level, such as a fan or a valve.

Consideration has been given to electrical design approaches that allow removal of electrical solenoids, transducers, etc., with complete isolation from the pneumatic and/or fluid systems. Attach fittings permit easy removal and installation of devices with minimum use of screws and bolts.

Filter elements are designed to permit exchange without releasing liquids or noxious gasses. The electrolysis cell stack is designed to be repaired at a module or subassembly level. If a single membrane fails, the entire module is replaced. Tanks are replaceable and are of a size that will pass through the passageways to the logistics docking port.

Two radiator control and two radiator recirculation assemblies are installed in the forward pressurizable equipment deck and two each in the unpressurized area between Decks 2 and 3. Both of these are maintainable in a shirtsleeve environment.

Acceptable repair times are limited to 30 percent of the critical (maximum possible) downtime to maximize the probability of repair. Note that critical downtimes for the EC/LS Subsystem will be very long, generally because of the two-compartment design.

Downtime allowable includes time for recognizing and locating the problem, isolation time, replacement/repair time, delay time in initiating maintenance, recharge and/or restart time, and checkout time to determine if the system is performing correctly.

To minimize crew error, installation of replacement components or modules is planned as one-way-possible positioning. Labeling and coding should be employed liberally to aid maintenance.

System design will emphasize commonality to reduce the number and types of spares and, thus, crew training requirements.

Maintenance ends ordinarily at the component level. However, consideration will be given to possible emergency repairs below the component level by use of standard parts where feasible.

Components shall be designed to be replaceable by one man. Modules, if required, may be replaced by two men.

External (outside the vehicle) maintenance will be at a higher level than internal maintenance (i.e., module, subsystem, or system rather than component replacement).

Hazardous maintenance (atmospheric contamination) and external maintenance (radiators) will be performed in a pressure suit, and subsystems are designed to permit this kind of maintenance.

Components are isolated, removed, and replaced as follows:

- Low-Pressure Air Line - Simple clamp removal, no isolation required
- High-Pressure Gas - Manually operated, isolation valves
- Fluid Lines - Special low leakage, component bypass maintenance disconnects

Small components can be removed and replaced simultaneously, with the loss of a maximum of 0.1 cc of water, by an installation tool that pushes the replacement components into the manifold. The replacement component, in turn, pushes the failed component into an empty sleeve. Large components are replaced by using the installation tool (plug) to remove the component and plug the manifold.

All equipment deemed critical to Space Station operation is duplicated so that cooling can be provided by either core module coolant water circuit. This system redundancy, together with the large core module atmosphere volumes, generally precludes the need for rapid fault isolation and repair.

4.3.3.4 RF Communications

The RF Communications System is comprised of the High-Gain and Low-Gain Antenna Systems, transmitters and receivers, and modems which interface the transmitters and receivers with the analog distribution bus. Except for the High-Gain Antenna System which has the parabolic reflector, feeds, positioner, and low noise preamplifiers located at the end of a boom, and the low-gain antenna radiating elements which are located on the surface of the pressure shell, the RF communications assemblies are located in either pressurized or pressurizable compartments.

The high-gain parabolic antennas are designed to be rotated into the end docking port for maintenance. This requires the maintenance to be performed in a space suit, but in a more compatible work position. The maintenance must be planned in less than three-hour task elements because of portable life support suit (PLSS) use limits.

Although undesirable, the Low-Gain Antenna System elements require replacement by EVA. These elements are currently inaccessible from the interior of the station.

The transmitters, receivers, and interface modems are packaged in multiples of the 1.25-inch width of the standard 8 - x 9-inch electronic module described in DRL 13, Volume I, Book 2, Space Station Electronics. Where possible, the assemblies have been sized so as not to exceed more than four standard widths. A notable exception is the S-Band power amplifier. Adherence to this packaging concept should facilitate maintenance and handling.

4.3.3.5 Structures

The structure is designed to permit on orbit maintenance of all leaks and punctures. Hatch mechanisms including seals, tracks, and rollers are replaceable. The external hatch seals can be replaced in a pressurized volume by first docking a module to allow the docking well to be sealed and pressurized. The new seal can be tested for leakage prior to de-docking the module by pumping down the dock area. The same method is used to permit repairs of the docking struts and retraction mechanism. EVA is required for replacement of docking seals. Meteoroid punctures are repairable with internal patches on the smooth inner wall surfaces. Trade studies indicate that over 50 percent of the cabin wall is easily accessible. The low probability of puncture does not warrant weight for providing rapid access to the remaining wall areas. Access is possible with removal of equipment but the interior arrangement penalty for instantaneous access is not merited.

Inflatable door seals and door lock mechanisms for tunnel doors and interior doors for the EVA airlock are replaceable in a shirtsleeve environment. Windows may be replaced by use of a portable seal and mechanical arm box, without losing pressure. Leaks at the telescoping joints in the spoke will be sealed by local plugging. Mechanical drives for the PCU handling fixture, the cargo transfer fixture, isotope reentry vehicle (IRV) rotation mechanism, and experiment despin module are repairable by component replacement.

4.3.3.6 Electrical Power

The major maintenance activity for the Electrical Power Subsystem is associated with circuit breakers, switches, inverters, battery chargers, voltage regulators, etc. These are replaceable items, and also contain replaceable function modules, such as electronic circuit cards. Provisions are made for switching in spare voltage regulators, battery chargers, etc., to permit maintenance or replacement at connector plugs as required, except where flat wire circuits are used in consoles. The inverters, voltage regulators and battery chargers are bolted to cold plates using allen-head-type bolts and will require closely-controlled flat surfaces for contact to assure heat transfer.

Two spare power conversion systems (PCS) for the two operating PCSs of the Isotope/Brayton Electrical Power System are installed in the power module (part of the core module), along with the remote handling mechanisms, carriages, and closed circuit TV viewing links used for transferring the PCS during installation or interchange. The PCS has a 2 1/2-year design life. PCS exchange can be performed either remotely or locally; however, work in this unpressurized compartment must be accomplished in a space suit. The isotope reentry vehicle, including the heat source (HS), must be placed in the passive heat dump mode for dissipation of HS energy to space during the PCS transfer. IRV deployment for heat dumping is accomplished by rotation of the IRV hinge mechanism and IRV support ring out of the Space Station port and away from the heat source heat exchanger (HSHX) into a position 90 degrees (or more) away from the radiator in which it is cooled by radiation to space. The IRV/heat source is held in operating position by solenoid-operated shear pins which are positively retracted during the deployment sequence. (Subsequent to launch if PCS power is lost, the pins fail in a retracted position.)

In the event of an abort or to release the IRV and heat source from the Space Station for recovery, the shear pins are first released and the IRV/heat source is moved to the deployed position by preloaded springs. Then the IRV/heat source is removed from the Space Station at the hinge attachment to the support ring, using a number of explosive (squib-actuated) nuts.

When normal recovery by an advanced logistic system is to be accomplished, a remote manipulator on the Crew Cargo/Tug Module will extract the deployed IRV/heat source from the mounting and transfer it, first to the recovery support cradle, and then to the ALS cargo door opening while still contained within the recovery support cradle. All operations will be conducted to incur minimum exposure to the crew from the unshielded IRV/heat source, using remotely controlled manipulators and closed circuit TV observation.

4.3.3.7 Data Management Subsystem (DMS)

The DMS components are primarily electronic and, as such, are designed for maintenance by replacement of the standard electronics module (previously described) or multiples thereof.

Large data and program storage devices, i.e., tapes and discs, are electromechanical devices which will be derivatives of present day commercial equipment. These electromechanical devices are subdivided for maintenance into modules such as:

- Basic memory element modules
- Mechanical modules
- Electronic modules
- Power supply modules

Electronic modules for these devices are standard books or multiples unless operational or maintenance requirements dictate otherwise.

The image processing components are electromechanical-optical devices and are subdivided for maintenance into the following:

- Mechanical/optical modules
- Electronic modules
- Power supply modules

Again, the electronics will be electronic book type modules. The command/control and display group contains a conglomerate of equipment. Most electronics will be contained in the standard module. The cathode-ray-tubes will be containerized so that they can be handled in space with a minimum of hazard from implosion. Those peculiar circuits that require critical alignments to get the CRT to function will be packaged as a part of the CRT container. Alphanumeric displays, keyboards, function switches, and display light groups may also contain integral electronics to facilitate pre-installation adjustment, minimization of interface lines, and control of electromagnetic radiation. Where these factors are not pertinent, the electronics will be packaged in the standard book type modules.

All data management components will be located in pressurized (or pressurizable) compartments for shirtsleeve maintenance.

4.4 LINE REPLACEABLE UNIT ANALYSIS

General guidelines and criteria for the definition of LRUs were established and these along with the maintenance philosophies reported in Section 4-3 were used to determine at what level line maintenance would be performed. For the

Space Station Subsystems (less DMS) specific justification applicable to LRU selection for the particular subsystem under examination was derived from the guidelines and these justifications are presented along with the LRU listing. In the case of the DMS, a functional partitioning of the major subsystem components based on the ability to create a viable isolation method to that functional level was performed. The "functional LRUs" were then considered in the light of the standard electronic packaging scheme and actual LRUs were defined and listed. The method employed and the results achieved are discussed for both cases in the following sections.

4.4.1 SPACE STATION SUBSYSTEMS (LESS DMS)

The definition of Line Replaceable Units (LRUs) is keyed to repairing subsystems in an in-place configuration with the LRU being the smallest modular unit suitable for replacement. General factors considered in identifying subsystem LRUs include: (1) maintenance concepts developed and defined in Section 4.3; (2) the component-level failure rates delineated in the criticality analyses of Section 4.1; (3) the amount of crew time and skill required for fault isolation and repair; (4) resultant DMS hardware and software complexity; and (5) subsystem weight, volume, location, and interchangeability characteristics. Listings of LRUs and more specific justification for their selection follows.

4.4.1.1 Guidance, Navigation, and Control

Guidance, Navigation,and Control (GN&C) Subsystem LRUs are listed in Table 4-8. Their selection is influenced largely by the specialized functional characteristics of GN&C components and the state-of-the-art in their packaging.

Sensing devices used in the GN&C Subsystem are mainly electromechanical or electro-optical in nature, and are generally configured with a sensor and a separate electronics package. In addition, most precision sensing devices are mounted on or within a specially designed structure for tight alignment tolerances and environment control. Gimbal-mounted tracking sensors, for example, are replaced as a unit with the gimbals since the tight mechanical tolerances for the gimbals are expected to be only maintainable on the ground.

Electronic assemblies which interface with the sensors, actuators, and data acquisition equipment of the Data Management Subsystem consist of groups of similar or identical circuits. These are modularized and replaced at the module level to take advantage of having a common spare configuration for several functions.

Control Moment Gyro Assemblies (CMGs) are large electromechanical devices which are constructed for long life operation with tight mechanical tolerances. The only on-orbit repair capability planned for these assemblies is the replacement of torquer-resolver units. The mechanical tolerance level required for long CMG life requires further breakthroughs in design technology before bearings and rotor can be considered as being replaceable on orbit.

Table 4-8. Guidance, Navigation, and Control

LRU	Quantity Required	Quantity Standby Redundant
Horizon Detector	2	
Gyro Assembly		
Gyros	6	
Gyro Electronics Assembly	6	
Gyro and Accelerometer Mount Assembly	2	
Gyro Power Supply	2	
Horizon Sensor Assembly		
Horizon Sensors	4	
Horizon Sensor Mount Assembly	1	
Star Sensor Assembly		
Star Sensors	2	
Star Sensor Mount Assembly	2	
Star Tracker Assembly		
Star Trackers	2	1
Tracker Electronics Assembly	2	1
Tracker Mount Assembly	2	1
Landmark Tracker Assembly		
Landmark Tracker	1	1
Tracker Electronics Assembly	1	1
Tracker Mount Assembly	1	1
Accelerometer Assembly		
Accelerometer	1	1
Accelerometer Electronics	1	1
Rendezvous Tracker Assembly		
Tracker Assembly	4	
Gimbal Mount Assembly	4	
Electronics Assembly	4	
Docking Tracker Assembly		
Tracker Assembly	7	
Tracker Electronics Assembly	7	

Table 4-8. Guidance, Navigation, and Control (Continued)

LRU	Quantity Required	Quantity Standby Redundant
Alignment Monitor Assembly (Sensors)		
Signal Transceiver	2	
Signal Receiver	2	
Alignment Monitor Assembly (Experiments)		
Signal Receiver	2	
Signal Source	2	
Interface Electronics Assembly		
Inertial Sensor Buffer Module	2	2
Horizon Sensor Buffer Module	1	1
Stellar Sensor Buffer Module	1	1
Landmark and Alignment Sensor Buffer Module	1	1
Laser Tracker Buffer Module	2	2
CMG Control Buffer Module	4	4
Reaction Jet Control Buffer Module	2	2
Data Control Module	4	4
Jet Driver Electronics Assembly		
High Thrust Jet Driver Module	4	
Resistojet Control Module	4	
Backup Control Electronics Module		2
CMG Assembly		
CMG Rotor Gimbal Assembly	4	2
Torquer Assembly (Inner Gimbal)	4	2
Torquer Assembly (Outer Gimbal)	4	2
CMG Electronics Assembly		
CMG Rotor Control Modules	4	2
CMG Torquer Control Modules	4	2

4.4.1.2 Propulsion

Line replaceable units for the low thrust portion of the Propulsion Subsystem are listed in Table 4-9. High Thrust Propulsion Subsystem LRUs are listed in Table 4-10. Although considerable operational redundancy exists within the subsystem, the only elements that can be categorized as "standby redundant" are the low-thrust flow control assembly and the high-thrust pressure control assembly.

Primary criteria used in the selection of Propulsion Subsystem LRUs were component packaging, replacement frequency, and crew time and skill requirements. Also considered were the factors of parts commonality, DMS and instrumentation impacts, and LRU usage within the subsystem. Each subsystem component was analyzed to determine first if replacement might be necessary and second, if necessary, the optimum level of replacement in terms of minimizing impacts upon both crew and equipment. In all cases, the LRU has been selected so that a redundant capability exists to allow subsystem operation with an LRU removed. Some performance degradation or partial loss of flexibility is, of course, permitted in this situation.

Except where components are packaged together to minimize mechanical joints and connections, most Propulsion Subsystem LRUs are individual components. Another exception is the power distribution and control assembly. Lower level replacement is anticipated for this LRU when more detailed design information becomes available.

4.4.1.3 Environmental Control and Life Support

A list of LRUs for the Environmental Control and Life Support (EC/LS) Subsystem is provided in Table 4-11. Replacement is at the component level primarily for efficiency of sparing and maintenance. It is at the component level where: (1) EC/LS elements are expected to require periodic replacement, (2) the number of EC/LS functions interrupted when maintenance is performed is acceptable, (3) only conventional tools are required, and (4) normal fabrication breakpoints exist. Lower level replacement would cause a disproportionate increase in instrumentation and in the complexity of tools and skills required. Higher level replacement would result in increased spares weight and volume due to a decrease in commonality of spares. For the EC/LS Subsystem, component-level LRUs offer a good compromise for the advantages and disadvantages of lower and higher level replacement.

4.4.1.4 RF Communications

A listing of LRUs for the RF Communications Subsystem is provided in Table 4-12.

Table 4-9. Low-Thrust Propulsion

LRU	Quantity
Collection/Storage Assembly	
Compression Pump	4
Propellant Storage Bottle	4
Filter	4
Relief Assembly	4
Tank Isolation Valve	4
Control Valve Assembly	2
Low Pressure Mixing Valve	2
High Pressure Mixing Valve	2
Water Supplement Assembly	
Storage Bottle	2
Water Vaporizer	2
Thermal Control Assembly	2
Fill/Drain Valve	1
Tank Isolation Valve	2
Flow Control Valve	2
Pressure Control Valve Assembly	2
Flow Control Assembly	
Regulator Assembly	2
Regulator Isolation Valve Assembly	2
Cross-feed Valve Assembly	1
Thruster Assembly	
Module Isolation Valve	8
Thruster Assembly	8
Power Distribution and Control Assembly	1

Table 4-10. Hi-Thrust Propulsion

LRU	Quantity
Press Storage Assembly (3000 psia GN_2)	
Storage Sphere	2
Relief Valve	2
Burst Disk	2
Isolation Valve	2
Pressure Transducer	2
Temperature Transducer	2
Hi-Press Manifold	
Isolation Valve	3
Vent Valve	2
Pressure Transducer	2
Filter Assembly	2
Disconnect Assembly	1
Press Control Assembly	
Regulator	2
Isolation Valve	2
Press Switch (hi/lo)	4
Filter	2
Lo-Press Manifold	
Isolation Valve	2
Press Transducer	2
Vent Valve	1
Disconnect Assembly	1
Propellant Storage Assembly	
Prop Tanks (Metal Bellows)	2
Relief Valve	2
Burst Disk	2
Isolation Valves (Prop and Ullage)	4
Press Transducer	4
Temperature Transducer	4
Qty Gauging (Assembly/System)	2

Table 4-10. Hi-Thrust Propulsion (Continued)

LRU	Quantity
Propellant Manifold	
Isolation Valve	6
Fill Valve	1
Vent Valve	1
Purge Valve	1
Press Transducer	3
Filter Assembly	1
Prop Dump Assembly (Nonpropulsive Prop Decomposition)	1
Disconnect Assembly	1
Thruster Modules	
Thruster Assembly	12
Isolation Valve	10
Filter Assembly	4
Press Transducer (liquid)	10
Press Transducer (Comb Chamber)	12
Temperature Transducer (Comb Chamber)	12
Purge Assembly	
Press Sphere	2
Regulator	1
Isolated Valves	8
Press Transducers	4
Resupply Assembly (Station)	
Isolation Valve (Press and Props)	4
Umbilical Hoses	4
Disconnect Assembly	4
Filters	4
Miscellaneous Assembly (allocation)	
Heaters	50
Thermostats	50
Temperature Transducer	30
Piping Assembly	50

Table 4-10. Hi-Thrust Propulsion (Continued)

LRU	Quantity
Cargo Module Resupply Subsystem	
Press Resupply	
Storage Spheres	2
Relief Valve and Burst Disk Assembly	2
Isolation Valve	2
Regulator	2
Press Transducer	2
Temperature Transducer	2
Disconnect and Umbilicals	2
Propellant Resupply	
Prop Tanks	2
Isolation Valves	2
Relief/Burst Assembly	2
Press Transducer	2
Temperature Transducer	2
Disconnects and Umbilicals	2

Table 4-11. Environmental Control and Life Support

LRU	Quantity Required	Quantity Standby Redundant
High Pressure Gas Tank	12	
Flow Restrictor	30	
Shutoff Valve, Solenoid W Manual OR	27	
Quick Disconnect	95	
3-Way Valve, Electrically Operated	34	
Electric Heater	20	
Pressure Regulator with Relief	2	2
Pressure Control	1	1
O_2 Sensor	1	1
3-Way Valve, Pressure Actuated	1	1
Shutoff Valve, Manual	275	
Relief and Dump Valve	2	2
Low Pressure Tank	9	
Pressure Regulator	5	
Compressor	9	
Heat Exchanger, Liquid to Gas	2	
Check Valve	40	
Air Bypass Valve	2	
Fan	20	
Pump	33	7
Condensing Heat Exchanger	8	
Temperature Controller	7	
Temperature Sensor	8	
Adsorption Cannister	19	
CO_2 Sensor	8	

Table 4-11. Environmental Control and Life Support (Continued)

LRU	Quantity	
	Required	Standby Redundant
Catalytic Bed	5	
Shut-Off Valve, Solenoid	69	
4-Way Valve, Electrically Operated	26	
Pressure Relief Valve	22	
Valve Sequence Controller	2	
CO_2 Demand Control	2	
Pressure Switch	4	
Flow Regulator	2	
CO_2 Conversion Controller	2	
Cold Plate	20	
Water Electrolysis Controller	1	1
Gas-Liquid Separator	14	
Electrolysis Module	12	12
Temperature Control Valve	19	7
Fluid Tank	10	10
Regenerative Heat Exchanger	9	1
Urine Water Recovery Controller	1	1
Conductivity Sensor	2	2
Quantity Sensor	8	8
Evaporator	1	1
Chemical Injector	2	2
Bacteria Filter	26	6
3-Way Valve, Manual	18	
Feed Tank	1	1
Wash Water and Condensate Recovery Control	1	1

Table 4-11. Environmental Control and Life Support (Continued)

LRU	Quantity Required	Quantity Standby Redundant
Solids Sensor	1	1
Reverse Osmosis Cartridge	1	1
Water Storage Control	1	1
Water Cooler	1	1
Potability Test Kit	1	1
Urine Collector	5	5
Fecal Container	2	2
Fecal Deflector and Motor	2	2
Fecal Collector Control	2	2
4-Way Valve, Manual	2	2
Fecal Collector Seat Cover and Seal	2	2
Pressure Gauge	2	2
Portable Life Support System (PLSS)	2	2
Oxygen/Coolant Umbilical	12	
IVA Control Module	12	
Oxygen Manifold	8	
Coolant Manifold	16	
Coolant Accumulator	12	
Coolant Water Filter	12	12
Liquid-to-Liquid Heat Exchanger	5	8
Thermal Control System Controller	2	
Thermal Capacitor	2	2
Temperature Sensor	4	

Table 4-12. RF Communications

LRU	Quantity Required	Quantity Standby Redundant
Transmitter/Receiver/Modem/Group		
S-Band Video Receiver	10	
Video Receiver Modem	10	
S-Band Data Receiver	10	
S-Band PM Receiver	2	
K_u-Band FM Exciter	2	
FM Xmtr Modem	2	
S-Band FM Receiver	2	
Receiver Modem	2	
K_u-Band PA	5	
K_u-Band PM Exciter	5	
S-Band PM Transponder	2	
Transponder Modem	2	
S-Band Power Amp	2	
S-Band FM Exciter	2	
Transmitter Modem	2	
VHF Voice Ranging T/R	2	
Ranging Modem	2	
Voice Modem	2	
VHF Data T/R	2	
VHF-FM T/R	6	
Modem	2	
Low-Gain Antenna Group		
VHF Antennas	4	
VHF Diplexers	4	
VHF Multiplexer, Power Dividers and Switches	2	
S-Band Antennas	4	
S-Band Triplexer and Switches	2	
K_u-Band Antennas	8	
K_u-Band Preamp/Mixer/Diplexer/Switches	2	
S-Band Multiplexer and Circulator	2	
K_u-Band Waveguides	8	
VHF/S-Band Coaxial Cables	8	

Table 4-12. RF Communications (Continued)

LRU	Quantity	
	Required	Standby Redundant
High-Gain Antenna Group		
Main Reflector/Feed	4	
Acquisition Reflector/Feed	4	
Pseudo Monopulse Comp/Mod.	8	8
Positioner		
Drive Motors	8	
Drive System	8	
Electronics	8	8
K_u-Band TDA/Mixer/L.O.	8	8
RF Switches (External)	2	
RF Switches (Internal)	8	
K_u-Band Quadriplexers and Circulators	4	
K_u-Band Diplexer	1	
S-Band Quadriplexer and Power Divider	4	
S-Band Diplexer	1	
K_u-Band Waveguides	4	

The transmitters (exciters and power amplifiers), receivers, and interface modems are selected as assembly-level LRUs largely because of packaging, reliability, and electromagnetic interference (EMI) considerations. These assemblies are packaged in multiples of the standard module size for mounting in the integrally-cooled mounting racks. Initial reliability estimates indicate that the power amplifiers are the most critical of this group of assemblies. Lower level modularization of the power amplifiers, however, is not practical because of restrictions caused by the physical dimensions of the Traveling Wave Tube (TWT), thermal cooling requirements, and sensitivity to changes in power supply voltages. It is planned, therefore, that the TWT and power supplies be mated and adjusted as a unit on the ground. Furthermore, lower level modularity would increase the number of connectors required, thereby decreasing overall reliability and creating potential sources of EMI. Another problem encountered with a lower replacement level is module-to-module tolerance buildup. This concept was attempted, for example, on an S-Band transponder for another program and resulted in modules not being interchangeable that were supposed to be interchangeable.

The primary considerations used in the selection of LRUs for the High- and Low-Gain Antenna Systems are somewhat different from those used for transmitters, receivers, and modems. Antenna system LRUs typically do not require thermal cooling and are consequently located largely on the basis of minimizing RF transmission line losses. The reliability of multiplexers, power dividers, coaxial cables, and the low-gain antenna elements is relatively high. The majority of the problems associated with Low-Gain Antenna (omnidirectional) Systems, if encountered, usually occur during initial installation and checkout. This is also true for similar components of the High-Gain Antenna System located within the pressure shell.

The most difficult maintenance and replacement problems are posed by the portion of the High-Gain Antenna System located at the end of the mast. If a failure occurs in the drive system, the drive system is replaced ~~in its entirety~~ to eliminate alignment problems. The drive motors, on the other hand, can be replaced separately in the event of failure. Redundant electronics are utilized wherever possible to minimize the high-gain antenna downtime.

4.4.1.5 Structures

Selection of LRUs for the Structures Subsystem is based primarily upon specific failure characteristics of subsystem comments. The selection has also been based upon a replacement level which can be accomplished with ordinary tools and skills, and without a requirement for precision alignment and/or special processes, environment, or facilities. The analysis has resulted in the LRU list shown in Table 4-13.

Table 4-13. Structures

LRU	Quantity
Docking Mechanism Shock Struts	64
Docking Port Inflatable Seals	14
Hatches and Airlock Doors Inflatable Seals	18
Inflatable Airlock	1
View Port Window Assembly	25
Hatch Temperature Indicators	32
Hatch Pressure Indicators	32
Hatch Assembly	16
Despin Module Drive Unit	1
Cable Deployment Module Drive	1
Docking Port Seal Latches	32
Antenna Boom	4
Antenna Boom Drive Unit	4
Cargo Handling Hoist	2
Cargo Hoist Cable	2
Electric Drive Unit, Isotope System Handling	2
Handling Aids, Isotope System	4

The LRUs defined fall into the following general failure categories:

- Soft Parts subject to scuffing, wear, puncture, possible age degradation, or other surface marring. Examples include hatch seals, struts with "O" rings, the inflatable airlock, and view port windows.

- Items subject to physical damage from outside physical impact/collision (e.g., docking) or misuse. Examples include docking latches, the antenna boom, the complete hatch assembly, and isotope unit handling aids.

- Functional electromechanical units which, during the ten-year life of the Space Station, could experience unexpected wear or internal part failure. Examples include the despin module antirotation drive unit, the antenna boom drive unit, the cargo handling hoist assembly, and the electric drive unit used in handling the isotope.

4.4.1.6 Electrical Power

Discussion of the LRUs identified for the Electrical Power Subsystem (EPS) is divided into two parts. The first is concerned with EPS transmission, conditioning, and distribution equipment, while the second addresses the Isotope/Brayton System.

4.4.1.6.1 Transmission, Conditioning, and Distribution

The EPS transmission/conditioning/distribution (T/C/D) LRUs are listed in Table 4-14 and consist of conductors, conductor terminations, relays, circuit breakers, limiters (fuses), power conditioners, and power control and instrumentation elements.

Main ac power feeder circuits are comprised of individual 4-conductor cables having relatively large cross-sectional areas. Both single-cable and multiple-cable circuits are employed. Spare cables complete with terminations are laid in place ready for connection into selected circuits in the event of a conductor/cable failure. This minimizes handling of large-gauge conductors and limits subsystem down time to the affected power circuit.

Differential and reverse current relays, circuit breakers, and switches (either electromechanical or solid state) are multiple usage items installed in panels and other higher-level bussing assemblies. They are selected as LRUs to reduce spares requirements and to minimize load circuit interruptions or power curtailment for either scheduled or unscheduled replacements.

Table 4-14. Electrical Power Transmission/Conditioning/Distribution

LRU	Quantity Required	Quantity Redundant
Alternator Feeders	2	2
Alternator Feeder Circuit Breakers	2	-
Alternator Feeder/Source Bus Differential Protection Relays	6	-
Alternator Feeder/Source Bus Phase - Balance Protection Relays	2	-
Source Bus to Distributor - No. 2 1200 Hz Transmission Cables	2	2 [2]
Distributor No. 2 to Distributor No. 1 - 1200 Hz Transmission Cables	2	1 [1]
1200 Hz Transmission Cable Differential Protection Relays	12	-
1200 Hz Transmission Cable Phase-Balance Protection Relays	4	-
1200 Hz Transmission Cable Current Breakers	8	-
1200 Hz Transmission Cable Power Switches	2	-
1200 Hz Transmission Cable Limiters (Fuses)	6	-
Main 1200 Hz Distributor Bus Differential Protection Relays	12	-
Main 1200 Hz Distributor Bus Phase-Balance Protection Relays	2 [2]	-
Main 1200 Hz Distributor Bus Power Switches	5	-
Main 1200 Hz Distributor Bus Selector Switches	3	-
Main 1200 Hz Distributor Bus Circuit Breakers	17	3
1200 Hz Feeders to Distribution Panels (Load Buses)	2	2
1200 Hz Distribution Feeder Circuit Breakers	2	2
1200 Hz Load Line Circuit Breakers	$\simeq 10$	-
Main 28 Vdc Distributor Differential Protection Relays	4	-

Table 4-14. Electrical Power Transmission/Conditioning/Distribution (Continued)

LRU	Quantity Required	Quantity Redundant
Main 28 Vdc Distributor Bus Sectionalizing CBs	2	-
Main 28 Vdc Distributor Bus Power Switches	12	2(4)
Main 28 Vdc Distributor Bus Reverse Current Relays	12	2(4)
28 Vdc Bus Tie Cable	1	1(1)
28 Vdc Bus Tie Cable Circuit Breakers	2	-
28 Vdc Feeders to Distribution Panels (Load Buses)	10	8(4)
28 Vdc Distribution Feeder Circuit Breakers	10	8(4)
28 Vdc Load Line Circuit Breakers	≃500	≃75 for essential loads only
260 Vdc Link Bus Differential Protection Relays	2	-
260 Vdc Link Bus Circuit Breakers	3	3(4)
260 Vdc Link Bus Power Switches	2	2(4)
260 Vdc Link Bus Reverse Current Relays	2	2(4)
260 Vdc Bus Tie Cable	1	1(1)
260 Vdc Bus Tie Cable Circuit Breakers	2	-
Main 400 Hz Distributor Bus Power Switches	6(5)	2(5)
400 Hz Square Wave Bus Tie Cable	1	1
400 Hz Square Wave Bus Tie Cable Circuit Breakers	2	-
400 Hz Square Wave Feeders to Distribution Panels	12	4(4)
400 Hz Square Wave Distribution Feeder Circuit Breakers	12	4(4)
400 Hz Square Wave Load Line Circuit Breakers	≃25	~20
400 Hz Sine Wave Bus Tie Cable	1	1(1)

Table 4-14. Electrical Power Transmission/Conditioning/Distribution (Continued)

LRU	Quantity Required	Quantity Redundant
400 Hz Sine Wave Bus Tie Cable Circuit Breakers	2	-
400 Hz Sine Wave Feeders to Distribution Panels	12	4 (4)
400 Hz Sine Wave Distribution Feeder Circuit Breakers	12	4 (4)
400 Hz Sine Wave Load Line Circuit Breakers	$\simeq$25	$\sim$20
Main 60 Hz Distributor Bus Power Switches (Single Pole)	2	-
60 Hz Bus Tie Cable (Single Phase)	1	1 (1)
60 Hz Bus Tie Cable Circuit Breaker (Single Pole)	1	-
60 Hz Feeders to Distribution Panel (GPL Only)	1	1 (2)
60 Hz Distribution Feeder Circuit Breakers (GPL Only)	$\simeq$10	-
60 Hz Bus Sectionalizing and Load Line CBs (GPL Only)	$\simeq$10	-
600 Hz Starting Bus Circuit Breakers (Interlocked)	1	2
600 Hz Starting Bus Selector Switch	1	1
600 Hz Transmission Cable from M-G in Distribution Center No. 1 to Starting Bus in Distributor Center No. 2	1	0
600 Hz Transmission Cable to Alternator No. 1	1	0
600 Hz Transmission Cable to Alternator No. 2	1	0
600 Hz Motor Generator (M-G) Set	1	1
Motor-Generator Input CBs (28 Vdc)	1	1
Regulated Transformer-Rectifiers (28 Vdc)	4	1 (4) (6)
High-Voltage Rectifier Regulator (260 Vdc)	2	2 (4) (6)
400 Hz Square Wave Inverter	1	1 (4) (6)
400 Hz Sine Wave Inverter	1	1 (4) (6)
60 Hz Sine Wave Inverter (Single Phase)	1	1 (4) (6)

Table 4-14. Electrical Power Transmission/Conditioning/Distribution (Continued)

LRU	Quantity	
	Required	Redundant
Launch and Ascent/Emergency Inverter (400 Hz Sine Wave)	1	1 (6)
Launch and Ascent/Emergency Inverter Input CBs (28 Vdc)	1	1
Battery Charger Regulator	10	
Battery	10	
Battery Switching Unit	10	
Buck Regulator (Regulates battery discharge voltage)	10	
Battery Emergency Override Control Circuit Breaker	10	
Power Control Modules (Power Management Assembly)	TBD	TBD
Instrumentation Sensors	TBD	TBD
Signal Conditioning Units	TBD	TBD

(1) Laid-in spare
(2) Operating redundancy
(3) Bus No. 2 only
(4) Standby redundancy
(5) Combined requirements for 400 Hz sine wave and square wave buses. Includes two square wave sine wave bus tie switches interlocked with outputs of emergency inverters.
(6) LRU may be at the component level in the noted modules.

Power conditioners (transformer-rectifiers, inverters, buck regulators, etc.) are typically "black box" end items. On-line redundancy is employed in the operation of these units. The T/C/D system is designed to permit quick replacement of these items in order to maintain operating redundancy/system reliability at required levels.

The design of power conditioning equipment generally lends itself to modularization and fault detection to the module level. Replacement of modules within power conditioners should be considered as an alternate to the "black box" LRU level where module commonality would permit economies-in-spares provisioning.

Typical LRUs for T/C/D instrumentation include sensors and signal conditioners for status display and power protection and control. The uniqueness of many T/C/D sensing devices in terms of location and rating (e.g., current transformers in transmission circuits, as well as distribution circuits, with primary ratings ranging from over 50 amperes to less than 1 ampere) establish these items as LRUs. Selected logic, amplification and possibly computational modules associated with power control are also candidate LRUs.

4.4.1.6.2 Isotope/Brayton

A listing of the isotope/Brayton LRUs is given in Table 4-15. Their selection is predicated on nuclear safety, life, and reliability considerations. They are also restricted to those assemblies and components which are readily replaceable and which are within the purview of projected crew skills and available tooling.

Isotope recovery requirements for nuclear safety dictate that the complete isotope reentry vehicle (IRV) heat source assembly be a line replaceable unit. Radiation hazard prevents any subassembly or component within the IRV heat source from being replaced. Therefore, all critical components and instrumentation are installed with adequate on-line and standby redundancy or alternate modes of operation to provide acceptable performance for the life of the IRV heat source. Typical examples are: (1) the dual hinges that allow the IRV heat source to open on either side for emergency cooling; and (2) the critical heat source temperature instrumentation having triple redundant sensors at both the capsule and on the BeO heat sink.

The Brayton Power Conversion System (PCS) is hermetically sealed for operation in the space environment. The complete PCS is replaceable as well as those PCS components that do not require the opening of working fluid lines. Replaceable components are therefore limited to surface thermocouples, solenoid valve electrical assemblies, and mounting fixtures. Replacement of internal components; e.g., rotating unit, heat exchangers, pressure gauges, and valve bodies, would require cutting and welding lines that operate at high temperatures and

Table 4-15. Electrical Power Isotope/Brayton System

LRU	Quantity Required	Quantity Standby Redundant
Isotope Reentry Vehicle Heat Source	2	
Power Conversion System	2	1
Solenoid Valve Electrical Assembly	12	6
Insulation	-	
Surface Thermocouple	26	13
Mounting Attachment	TBD	TBD
Heat Rejection System		
Pump Motor	8	
Transducers	44	
Cold Plate	6	
Diversion Valve	8	
Pump Motor Electrical Switch	8	
Insulation	-	
Gas Management System		
Heater Contactor	2	
Gas Storage Bottle	2	
Transducer	4	
Solenoid Valve Electrical Assembly	10	
Electronic Monitoring and Control Assembly		
Signal Conditioner Module	2	1
Speed Control and Dissipative Load Bank Unit	2	1
Voltage Regulator Exciter	2	1
Shield Assembly		
Shield	2	
Shield Retraction Cable	2	
Shield Retraction Sheave	2	
Shield Retraction Drive	2	

pressure. Extensive inspection, testing, and gas recharging would also be required before the system could be put back on-line. Attendant skills, tooling, and gas management capacity are not available in the baseline system to allow replacement at this level.

Unitized construction of the cooling tubes, meteoroid bumpers, and spacecraft structure as well as the length of radiator cooling tubes preclude classifying the Heat Rejection System as a line replaceable unit. In view of this, all components of the Heat Rejection System (e.g., sensors, pumps), with the exception of the radiator tubes, are made line replaceable. In addition, extensive redundancy is employed in the baseline system because of the complexity of removal and replacement of heat rejection components.

Gas Management System components are replaceable if they are upstream of the solenoid valves that isolate this system from the PCS. The jacking gas supply is paralleled with the second onboard Gas Management System during replacement to provide a continuous source of jacking gas to protect the journal and thrust bearing.

The electronic monitoring and control assembly is divided into three separate modules (Voltage Regulator/Exciter, Speed Control, and Signal Conditioning) which are independently packaged. The speed control portion is further divided into three LRUs, one to sense each phase of the 1200 Hz, 120 V, 12.5 kWe alternator output and apply or remove parasitic loading to maintain constant frequency under varying load and alternator output conditions. Each control circuit loads all three phases simultaneously. Each replaceable unit provides a total of six kilowatts of parasitic load so any one control circuit can be in the OFF position without affecting overall system performance.

The retractable shield is used for nuclear radiation reduction and is capable of being retracted to allow a thermal radiation path from the heat source to the inside of the spacecraft for emergency cooling. At launch, the heat shield contains 5 inches of LiH to meet the dose criteria for the first 2 1/2 years. Additional shielding of 3 inches of LiH and 0.2 inch of depleted U238 is required to meet the dose criteria for the period from 2 1/2 to 10 years.

4.4.2 DMS SUBSYSTEM

From the baseline DMS, the LRUs were defined and partitioned from the physical and functional considerations relative to each respective subsystem.

4.4.2.1 Functional Partitioning

Primary selection was generally on the basis of functional fault isolation capabilities. An approach was taken (Section 6.1, Volume II) whereby automatic (OCS) or semiautomatic (OCS/manual) methods could be employed to diagnose and isolate subsystem faults to a reasonable functional level. This functional level was chosen on the basis of experience and familiarity with the subsystem. The approaches presented in Section 6.1 could be expanded to greater levels of detail, even to the individual piece part level, but the requirements in terms of hardware and software necessary to implement these would increase exponentially. A reasonable rationale for the determination of the level of functional partitioning was defined as that functional level which is required for the intended normal operation of the subsystem without the necessity for considerable built-in test circuitry. Some functional LRUs defined herein include a degree of self-check capability. This was found to be required in terms of implementing the functional diagnostic/isolation approach derived without postulating additional separate "test boxes."

4.4.2.2 Physical Partitioning

Consideration was also given to the physical aspects of LRU definitions, in terms of the standard electronic book module defined in DRL 13, Volume I, Book 2. It appears that such a module, or a basic group of several modules, would be an ideal LRU in respect to replacement, logistics, ease of handling, etc., considerations. Indications are that a majority of the LRUs presented herein could be packaged in one or more "basic" modules. The Remote Data Acquisition Unit (RDAU) and Local Monitor and Display Unit (LMDU) electronics appear to be the smallest defined LRUs and would probably be packaged two to a basic module. These assessments are based on initial unit power estimates and module capabilities in addition to a "subjective" sizing of the circuitry required for a particular function. In the Command/Control and Display Consoles (CCDC), consideration was given to the packaging aspects of the control and display assemblies. These assemblies would be treated as separate LRUs, along with all their associated electronic circuitry. Due to the peculiar nature (keyboards, display lights, etc.) of these assemblies in respect to a "basic" module, they would be packaged as separate removable units. This would greatly enhance the isolation and maintainability of these assemblies.

4.4.2.3 Functional LRU Definition

In order to define a workable fault diagnostic/isolation scheme certain hardware requirements and subsystem functional diagrams were postulated. These requirements and functional diagrams are reasonable, in view of present and future technology, and are in concert with the overall baseline DMS philosophy. A detailed description of certain of these functional elements can be found in Section 3 "Baseline Subsystem Descriptions." The other functional elements are described in DRL 13, Volume I, Book 2, Space Station Electronics.

4.4.2.3.1 Computer Subsystem

The overall Computer Subsystem is comprised of the following functional elements:

- Operations Multiprocessor
- Experiment Multiprocessor
- Shared Memories
- Bulk Data Storage

The multiprocessor elements can be further broken down into the following elements, each of which is considered a functional LRU:

- Data Bus Controller (DBC) - A device, not unlike a data bus terminal, which is used by the DMS/OCS multiprocessors to issue commands to and receive data from the data bus.
- Switch Matrices - These are multiple channel switching circuit complexes which are completely transparent to any coding scheme.
- Input/Output Circuitry - These are multiple channel interface circuits which perform parity checks on all incoming data.
- Logic and Control Circuitry - This is the main arithmetic-control element of the CPU.
- Dedicated Memory - This is a memory which is peculiar to a given CPU. It cannot be addressed directly from any other DMS/OCS element. It is a high speed rapid access element which is used to store the immediate operating and executive routines for that CPU.
- Power Supply and Distribution - This power source provides all required operating power for the I/O, logic and control, and dedicated memory.

The shared memories, main and auxiliary, can be broken down to a lower level of isolation (LRU definition) by supplementing the automatic diagnostics described in Section 6.1 with manual procedures.

The following replaceable elements should be considered as actual LRUs.

- Electronics section - Contains I/O, logic, control circuitry, etc.
- Mechanical section (where applicable) - Contains disk drives, tape transports, etc.
- Memory element - Contains solid-state memory, disks, magnetic tape reels, etc.
- Power section - Contains power supplies, distribution, etc.

The bulk data storage elements can be further broken down into the following elements, each of which is considered a functional LRU:

- Digital Buffer and Control (DBC) - This unit provides the input/output and control functions for the bulk data storage facility. It decodes commands from the CPU and sets up the proper write/read channels through the various switch matrices.
- Record/Reproduce Electronics (R/R) - This element is a multichannel, switchable write/read unit. It conditions the data for transferral to and from the magnetic tape storage medium.
- Switch Matrices - These are multiple-channel switching circuit complexes which route signals (data or control) to appropriate hardware elements.
- Tape Transport Controller (TC) - These are the control circuits for the individual tape transports. They provide all the required read/write tape control under command from the DBC.
- Tape Transports (TT) - These are the magnetic tape drives. The tape drive motors and associated electromechanical elements comprise these units.
- Power Supply and Distribution - These units provide all the required power for the bulk data storage facility, with the exception of the DBT.

4.4.2.3.2 Data Acquisition

The Data Acquisition Subsystem is comprised of the following elements, each of which is considered a functional LRU.

It should be noted that the sensor assembly and the function under test are integral parts of the subsystem/experiment group and as such are not considered as data acquisition elements.

- Data Bus Terminal (DBT) - A device used to interface various subsystems and experiments (including RDAU and LMDU) to the data bus.
- Remote Data Acquisition Unit (RDAU) - This unit accepts analog and discrete inputs from various subsystems/experiments, converts these input to digital data, and interfaces directly with a data bus terminal.
- Stimuli Generation Unit (SGU) - This device, upon command from a data bus terminal, provides different calibrated signals (stimuli) to various subsystems/experiments. This is the only unit which is used primarily for diagnostic purposes.

4.4.2.3.3 Command/Control and Display

The Command/Control and Display Console (CCDC) is comprised of the following assemblies:

- Alphanumeric Display Assembly - Display for computer-generated digital data.
- Status Light Assembly - Display for computer-generated digital data. Used to indicate operational conditions.
- Dedicated Displays - Contingency displays hardwired to appropriate subsystems/experiments.
- Command Buffer and Control Unit - Provides control for the digital multiplexer in addition to buffering all the commands from the CCDC control panels. Contains a self-test feature.
- Digital Multiplexer - Combines all the CCDC control commands for inputting to the Command Buffer and Control.
- Hand Controller Assembly - Used for providing continuously variable human input information to the computer. Used in conjunction with the Mode Select Switches.

- Mode Select Switch Assembly - Used to establish the logic that determines the function of the multifunction pushbuttons.

- Multifunction Switch Assembly - Provides for the single selection of a group of commands.

- Monofunction Switch Assembly - Provides for the selection of individual commands.

- Computer Keyboard Assembly - Used for directing computer operations or modifying/correcting existing software routines.

These assemblies can be further broken down into the following elements which are considered as functional LRUs.

- Display Control and Buffer Unit - Provides control for the Display Switch Matrix in addition to buffering all display data to the CCDC.

- Display Switch Matrix - A multichannel switching matrix which routes display data to the appropriate displays.

- Refresh Buffer - Provides the necessary storage capability for the CRT displays.

- Display Control - Provides the primary control of what is being displayed on the CRTs. Can select between digital data or analog information for display. Control of video/Command Control television (CCTV) on the CRT displays is provided by this function.

- CRT Display Assembly - An integral unit containing the CRT and all necessary video control functions.

- Warning Annunciator Assembly - Contains an integral audio alarm along with all required visual displays for critical warning function alarming.

- Caution Display Assembly - Display for all critical caution functions.

- Discrete Controls - Contingency controls hardwired to appropriate subsystems/experiments.

- Microfilm Viewer Assembly - This unit provides the means to view stored microfilms.

- Microfilm Viewer Control - Provides the required control for microfilm retrieval and viewing.

- Microfilm File - Microfilm storage.

- Analog Interface Unit - This unit provides the capability for analog information (CCTV video, intercom audio, etc.) to be transferred to and from the CCDC. It interfaces the data bus with the CCDC circuitry.

- Channel Select and Analog Control - This unit provides the channel selection capability for CCTV and intercom distribution in addition to providing control for all CCDC analog functions.

- CCTV Panel Assembly - Primary setup and control point for all Space Station CCTV distribution.

- Intercom Control Panel - Primary setup and control point for all Space Station intercom distribution.

- Audio Tape Assembly - Audio tape control and deck assembly.

- Video Tape Assembly - Video tape control and deck assembly.

- Illumination Control Assembly - Provides Space Station ambient light control in addition to CCDC panel illumination and lamp test capabilities.

- CCDC Power Supplies - These units provide all the required power for the CCDC. An overall power system rationale has yet to be developed.

The Portable Display and Control Unit (PDCU) is comprised of the following elements all of which are considered functional LRUs.

- Display Assembly - Contains the refresh buffer, CRT display control, and CRT display assembly

- Computer Keyboard Assembly

- Optional Pluggable Features
  - Hand controller assembly
  - Multifunction switch assembly

- Power Supply - Provides all required power for the PDCU

4.4.2.3.4 Image Processing

The Image Processing Subsystem is comprised of the following elements, which are considered functional LRUs.

- Display Control - Provides the primary control of what is being displayed on the CRTs.
- CRT Display Assembly
- Film Viewer - Provides the capability to manually view processed films. Consists of a screen for viewing or scanning, controls, and frame counter.
- Film Scanner - Transforms film images into electrical analog signals.
- Image Digitizer - Converts analog signals from the film scanner and vidicon outputs into digital data.
- Adjustable Multichannel Filter - Provides the analog processing capability. The working analog storage function is an integral part of this unit.
- Permanent Analog Storage - Provides tape recording capability for the storage of analog data.
- Analog Control Assembly - Provides all the required control for the operation of the adjustable multichannel filter, display control, and permanent analog storage in respect to analog image data.
- Digital Control Assembly - Provides all the required control for the various digital components in the subsystem.
- Working Digital Storage - Provides a rapid access storage capability for digital information via the digital control assembly or the Data Bus Terminal.
- Permanent Digital Storage - Provides tape recording capability for the storage of digital data.
- Display Conversion - Used to convert digital data received from the computer into analog signals for viewing on the CRTs.
- Annotation and Editing Assemblies - Provides the capability for annotating and editing processed film, digitized images, or analog information. Specific hardware requirements for these functions have yet to be defined.

4.4.2.3.5 GN&C Preprocessors

A typical functional diagram for the GN&C preprocessors is shown in Figure 4-1. This figure is intended to be representative of the five GN&C preprocessors. These GN&C preprocessor elements are simplex dedicated digital computers with self-test capability, and are considered functional LRUs.

4.4.2.4 LRU Definition

The LRUs defined in this section are listed in Table 4-16 by their respective subsystems and are a result of the degree in which a software/hardware system (OCS) can effectively isolate malfunctioning elements (see Section 6) in addition to the physical considerations of packaging and accessibility within a given equipment complex.

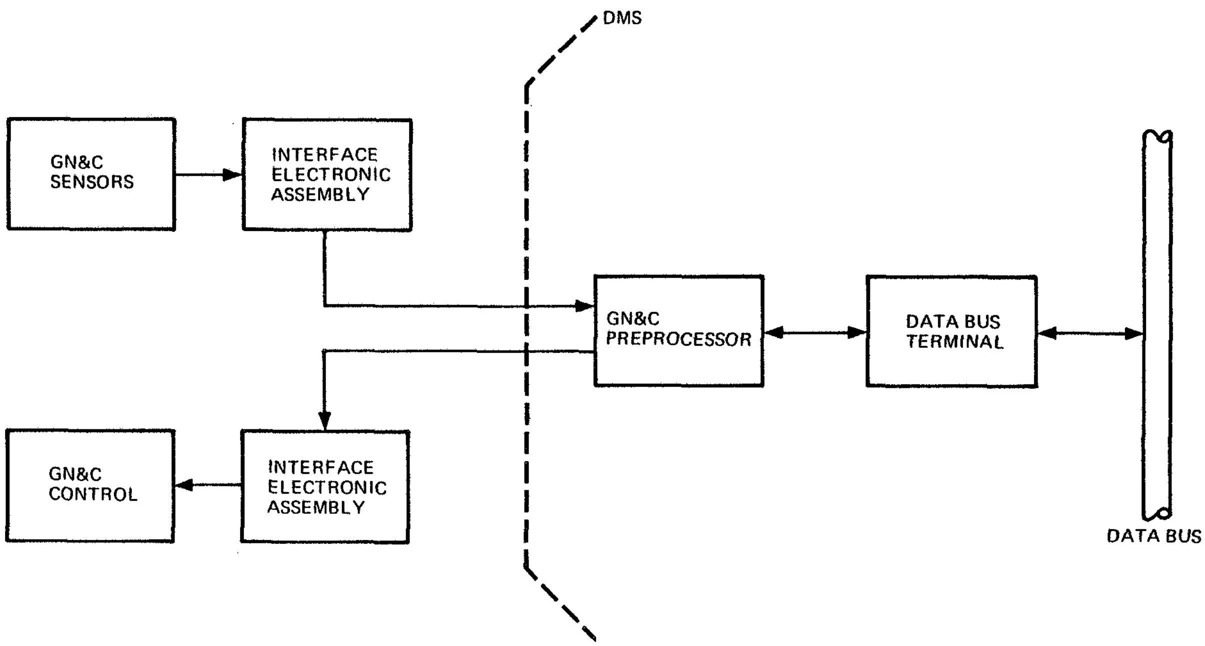

Figure 4-1. GN&C Preprocessor Typical Functional Diagram

Table 4-16. Data Management Subsystem

Item	Quantity
Computer Subsystem	
Data Bus Controller	2
Data Bus Switch Matrix	2
Memory Switch Matrix	2
Data Bus I/O	2
Shared Memory I/O	2
CPU Logic and Control	6
Dedicated Memory	6
CPU Power Supply	6
Shared Memory Electronics Section	2
Shared Memory Mechanical Assembly	2
Memory Elements	16
Shared Memory Power Supply	2
Bulk Data Storage	
Digital Buffer and Control	4
Record/Reproduce Electronics Assembly	4
Transport Switch Matrix	4
Controller Switch Matrix	4
Tape Transports	4
Tape Transport Controllers	4
Bulk Data Storage Power Supply	4
Data Acquisition	
Data Bus Terminal	30
RDAU (or LMDU)	250
Stimuli Generation Unit	40
Command/Controls and Display	
Display Control and Buffer	2
Display Switch Matrix	2
Refresh Buffer	2
Display Control	2
CRT Display Assembly	2
Warning Annunciator Assembly	2
Caution Display Assembly	2
Alphanumeric Display Assembly	2
Status Light Assembly	2
Dedicated Displays	2

Table 4-16. Data Management Subsystem (Continued)

Item	Quantity
Command Buffers and Control	2
Digital Multiplexer	2
Hand Controller Assembly	2
Computer Keyboard Assembly	2
Mode Select Switch Assembly	2
Multifunction Switch Assembly	2
Monofunction Switch Assembly	2
Discrete Controls	2
Microfilm Viewer Assembly	2
Microfilm Viewer Control and File	2
Analog Interface Unit	2
Channel Select and Analog Control	2
CCTV Panel Assembly	2
Intercom Control Panel Assembly	2
Audio Tape Assembly	2
Video Tape Assembly	2
Illumination Control Assembly	2
CCDC Power Supplies	2
Portable Display and Control Units	
Display Assembly	4
Computer Keyboard Assembly	4
Optional Pluggable Functions	4
Power Supply	4
Image Processing	
Display Control	1
CRT Display Assembly	1
Film Scanner	1
Film Viewer	1
Image Digitizer	1
Adjustable Multichannel Filter	1
Permanent Digital Storage	1
Working Digital Storage	1
Permanent Analog Storage	1
Digital Control Assembly	1
Analog Control Assembly	1
Display Conversion	1
Annotation and Editing	1
GN&C Preprocessors	
GN&C Preprocessor	5

Section 5

OCS CHECKOUT STRATEGIES

5.1 SUBSYSTEM CHECKOUT STRATEGY

Prior to any further requirements analysis, it is necessary to develop a checkout strategy for all Space Station subsystems to meet the checkout objectives of the Space Station OCS. The objectives of the Space Station OCS can be summarized as follows:

- To increase crew and equipment safety by providing an immediate indication of out-of-tolerance conditions
- To improve system availability and long-life subsystems assurancy by expediting maintenance tasks and increasing the probability that systems will function when needed
- To provide flexibility to accommodate changes and growth in both hardware and software
- To minimize development and operational risks

Specific mission or vehicle-related objectives which can be imposed upon subsystem level equipment and subsystem responsibilities include:

- OCS should be largely autonomous of ground control.
- Crew participation in routine checkout functions should be minimized.
- The design should be modular in both hardware and software to accommodate growth and changes .
- OCS should be integrated with, or have design commonality with, other onboard hardware or software .
- The OCS should use a standard hardware interface with equipment under test to facilitate the transfer of data and to make the system responsive to changes.
- Failures should be isolated to an LRU such that the faulty unit can be quickly removed and replaced with an operational unit.

- A Caution and Warning System should be provided to facilitate crew warning and automatic "safing" where required.

- Provisions must be included to select and transmit any part or all of the OCS test data points to the ground.

To attain these objectives via the use of an Onboard Checkout System which is integrated with the Data Management System, checkout strategies have been developed which are tailored to each Space Station subsystem.

Special emphasis has been applied to a strategy for checkout of redundant elements peculiar to each subsystem. The degree to which each of these functions is integrated into the DMS is also addressed.

5.1.1 SPACE STATION SUBSYSTEMS (LESS DMS)

Each major Space Station subsystem was examined with respect to the required checkout functions. The checkout functions associated with each subsystem are identified and analyzed as to their impact on the onboard checkout task. The functions considered are those necessary to verify operational status, detect and isolate faults, and to verify proper operation following fault correction. Specific functional requirements considered include stimulus generation, sensing, signal conditioning, limit checking, trend analysis, and fault isolation.

5.1.1.1 Guidance, Navigation, and Control Subsystem

The Guidance, Navigation, and Control (GN&C) Subsystem contains the sensors, including gyroscopes, accelerometers, horizon sensors, star trackers, and landmark trackers, and the associated electronics required to provide attitude stabilization and navigation for the Space Station. The subsystem also includes laser devices for rendezvous and docking.

5.1.1.1.1 Checkout Functions

Checkout and fault isolation of the GN&C Subsystem involves a combination of operational limit and validity checks and functional testing. Normal operational monitoring utilizes the inherent self-verification capability of the subsystems which accrues from redundant and complementary attitude and navigational sensing features. Items such as gyros, accelerometers, horizon sensors, star sensors, star trackers, and landmark trackers are implemented redundantly, allowing cross-correlation of outputs from the multiple units. Further, certain of these sensors are complementary to each other, allowing an additional dimension of correlation. Star tracker outputs, for example, can be checked against landmark tracking data for validation. Fault isolation is accomplished by majority voting techniques and by input/output functional testing using combinations of normal operational functions and artificial test stimuli. Examples of the latter include a simulated star source which is part of the star tracker assembly, torquing coils for stimulation of gyro outputs, and sensor output simulation signals for verification of downstream electronics. Other forms of operational monitoring include limit testing and trend analysis of selected performance parameters.

- Stimulus Generation - Checkout stimuli are required to perform periodic subsystem functional tests and calibrations and to aid in fault isolation to the LRU level. Typical stimuli include gyro torquing signals, simulated detector outputs for the horizon sensors, star sensors, star trackers, landmark trackers, accelerometers, and various test stimuli for the associated electronics packages such as the jet driver logic. These are in addition to the normal control signals such as switching and gimbal commands.

- Sensing - A detailed listing of measurement requirements is included in Appendix I.

- Signal Conditioning - Measurement signal conditioning is required to normalize the sensor outputs listed above. The required conditioning circuitry is provided as an integral part of the sensor assembly or in the Interface Buffers which provide the interface between the attitude and navigational sensors and the preprocessors.

- Limit Checking and Trend Analysis - Continuous or periodic limit checking is required on a small number of parameters such as gyro temperature and CMG rotational speed, vibration, and bearing temperature. Trend analysis of the CMG functions is expected to be meaningful in predicting wearout or failure of these units.

5.1.1.1.2 Redundant Element Checkout

Redundancy in the GN&C Subsystem is predominantly in the form of installed and operational equipment such as redundant accelerometers, horizon sensors, star trackers, etc. The redundant equipment is normally on line and is implemented in such a way that it can be tested independently without disturbing system operation. It therefore presents no special problems from the checkout standpoint. An exception is the spare CMGs, which are installed in a standby (nonoperating) condition. The standby units must be tested periodically to assure availability. This periodic test will consist of a partial spin-up and gimbal check. Full speed spin-ups are not planned because of the long time (several hours) required to achieve rated speed and because full speed is not necessary to verify operation.

5.1.1.1.3 Integration with Data Management Subsystem

All control functions as well as the test sequencing and fault isolation for the GN&C Subsystem are performed by the DMS computer. Test stimuli generators and measurement signal conditioning are contained in the GN&C Subsystem. The subsystem interfaces with the DMS through the GN&C interface buffers. These buffers receive control information from the DMS in digital form and provide the necessary logic, signal routing, digital-to-analog conversion, and other functions required to control the GN&C equipment. The buffers also provide the multiplexing and analog-to-digital conversion required to translate the GN&C equipment outputs to digital formats compatible with the DMS interface.

5.1.1.2 Propulsion Subsystem

The Propulsion Subsystem consists of two major elements, one being the low thrust resistojet system and the other the high-thrust monopropellant Hydrazine System. Both systems interface with the GN&C Subsystem and the Data Management Subsystem for control. In addition, the low-thrust system interfaces with the EC/LS Subsystem for biowaste propellants.

5.1.1.2.1 Checkout Functions

Checkout functions associated with the Propulsion Subsystem include continuous monitoring of critical parameters, short interval limit and status checking, and longer interval periodic in-depth testing to ascertain overall system health. The continuously sampled parameters include storage tank, regulator outlet, and manifold pressures, biowaste compressor pump speed, and heat exchanger temperature. Other critical parameters, such as thruster head temperature and resistojet heater power, also require high rate monitoring, but only at selected times, i. e., during thruster operation. Less critical system parameters including valve positions, propellant quantities, and secondary pressures and temperatures are checked on a low rate or as-required basis to verify system status. In-depth testing is performed on a scheduled periodic basis or in conjunction with fault isolation and includes functional tests of valves, regulators, pumps, and other active components. Fault isolation is accomplished by combinatorial analysis of operating conditions and by functional testing.

- Stimulus Generation - Functional testing and fault isolation of the Propulsion Subsystem utilize the normal operating controls, such as valve actuation commands to establish the desired test conditions and to initiate functions to be tested. No additional stimulus requirements have been identified.

- Sensing - The sensing requirements associated with the Propulsion Subsystem are contained in Appendix I.

- Signal Conditioning - Signal conditioning is required for all sensor outputs which do not fall within the standard measurement capability of the Remote Data Acquisition Units. The exact quantity and type of conditioning channels required are dependent upon sensor selection. Parameters such as valve position and event measurements are normally implemented as directly compatible bilevel voltages and require no special conditioning.

- Limit Checking - There are two types of limit checking required by the Propulsion Subsystem. The first is the continuous limit checking required in the case of critical but relatively static parameters, examples of which are tank, regulator output and manifold pressures, and heat exchanger temperatures. Out-of-limit conditions in these parameters indicate the need for relatively expedient relief or corrective action such as pressure venting which, depending upon the circumstances, may be either manually or automatically initiated. A second class of limit checking is associated with dynamic functions to which significant limits apply only during certain operating conditions, such as during thruster firing. Examples include thruster heat temperature and chamber pressure. Detection of an out-of-limit condition in these cases generally dictates termination of the operation or switching to an alternate mode. It is apparent from the foregoing that the requirement exists for selectively enabling and disabling the limit check on various parameters.

- Trend Analysis - Trend analysis has potential benefit in predicting end of life for wearout items in the system. The most promising application is in association with the biowaste resistojet thrusters. These units operate at very high temperatures using corrosive propellants, and therefore must be replaced from time to time. Typical failure modes include corrosion of the electrical heating elements and erosion or blockage of the nozzles. Long-term analysis of thruster power consumption, temperatures, and pressures are expected to yield information indicative of such failures. Trend analysis of another form is utilized to keep track of propellant and pressurant usage in both the low-thrust and high-thrust systems as an aid to controlling resource utilization and resupply operations.

5.1.1.2.2 Redundant Element Checkout

Redundancy in the low-thrust system is provided by two parallel systems from the EC/LS interface to the thrusters. These parallel systems each contain the valving, compression pumps, regulators, and storage tanks necessary to allow independent operation. Cross feeds and isolation valves are provided to allow interconnection of the two systems at various points if desired. This design also allows the two systems to be checked out and operated independently and allows bypassing or isolation of defective components for purposes of repair or replacement. The thrusters feature functional redundancy in that multiple thrusters or thruster pairs are capable of supplying any desired moment to the vehicle. These multiple units are also capable of independent checkout. Checkout of the redundant elements is therefore readily accomplished and presents no unique problems.

The high-thrust system also features redundancy in the form of multiple storage tanks, pressure regulators, and thrusters. The storage tanks and thrusters are isolatible by valving and may be exercised independently. The High Pressure Nitrogen Regulation System contains parallel regulators, one primary and one on standby, with automatic switchover via pressure switch interlock. Switchover to the secondary regulator may also be initiated by command, thus enabling checkout of the backup unit.

5.1.1.2.3 Integration with Data Management System

The checkout interface between the Propulsion Subsystem and the DMS consists of the measurement parameters listed in Appendix I. All measurements at the interface are in the form of normalized 0-20 mVdc, 0-5 Vdc, or 0-28 Vdc. No special test stimuli are required. Test sequencing and control as well as operational control and display, are provided by the DMS.

5.1.1.3 <u>Environmental Control and Life Support Subsystem</u>

The Environmental Control and Life Support Subsystem (EC/LSS) is perhaps the most critical of the onboard subsystems in that its proper operation is essential to the habitability of the Space Station and to the lives of the crew. The subsystem therefore features a high degree of reliability which is achieved through conservative design and through redundancy and backup provisions. Major elements of the subsystem are the atmosphere supply and control, atmosphere reconditioning, water management, waste management, IVA/EVA, and thermal control systems.

5.1.1.3.1 Checkout Function

The EC/LSS is a mechanical and chemical subsystem and as such involves some rather unique checkout and fault isolation considerations. Probably the most apparent of these is the extremely wide spectrum of sensing requirements. These range from the relatively common, such as voltage, temperature, and pressure, to the uncommon which include PH factor and conductivity of water. Other significant characteristics of the subsystem from the checkout standpoint are its large size, wide physical distribution, and its complexity.

The subsystem performance parameters, (pressure, temperature, flow, quantity, etc.) are predominatly analog in nature and are associated with continuous process operations rather than events. Such parameters lend themselves well to limit checking as a means of status monitoring and fault detection, and this technique is used extensively. Some trend analysis is also utilized to evaluate performance of limited life items such as filters. Fault isolation is accomplished primarily through combinatorial analysis of operating conditions.

- Stimulus Generation - No external stimuli other than those required for operational control are required for checkout of the subsystem.

- Sensing - Detailed measurement requirements are included in Appendix I.

- Signal Conditioning - Many sensors will impose requirements for signal conditioning to convert their outputs to a form compatible with the data acquisition equipment. The exact quantity and configuration will depend upon the type of sensors selected, but may include strain gauge and temperature probe conditioning, frequency to DC conversion, etc., plus scaling, amplification, and buffering circuitry. The required circuitry is provided as an integral part of the sensor assemblies or in associated electronics assemblies.

- Limit Checking - The EC/LSS involves a large number of fluid process functions such as temperature and pressures which must be monitored to assure the proper operation and safety of the subsystem. This requirement leads to the extensive use of a limit checking technique. The applicable limits include both absolute limits, such as those associated with safety, and operational limits which may vary in accordance with particular operating modes or conditions. Certain parameters have significant limits in both categories and therefore require a dual limit check. The variable aspect of the operational limits necessitates the capability for selectively altering the limit criteria in real time.

In terms of data processing requirements the large number of limit functions associated with the EC/LSS is offset to some extent by the relatively low rates involved. The majority of these functions are dynamically stable and are not subject to high rates of change. The sampling rate may therefore be quite low (i. e., one iteration/second or minute) even on the more critical functions which involve crew safety.

Detection of an out-of-limit condition in any of the EC/LSS parameters will lead to some form of relief or corrective action, either automatically or by the crew. The nature of the required action will in some cases be directly deducible, but more commonly must be determined through fault isolation techniques. A typical situation will involve a two-stage reaction, first to relieve the condition and then to correct it. An example is the detection of a sudden pressure decay in a freon coolant loop, indicating a possible rupture. Immediate and automatic action would be taken to isolate the loop to minimize further loss of fluid. This would be followed by automatic switchover to the alternate loop to maintain thermal conditioning. Fault isolation precedures would then be initiated to localize the problem and determine repair action.

- Trend Analysis - Trend analysis techniques will be utilized where applicable to accomplish predetection of potential failures or hazardous conditions and as an aid to the detection and diagnosis of abnormal conditions. Examples of predetection include monitoring of trace contaminants in the atmosphere to detect buildup trends and monitoring of CO_2 absorption bed moisture level to project useful life. The application of trend data to fault detection and diagnosis is illustrated by the use of nitrogen repressurization history to detect abnormal cabin repressurization rates which may be indicative of a leak in the vehicle pressure shell. Still another form of trend analysis is utilized in monitoring and forecasting consumables usage as an aid to resource management and resupply planning.

- Fault Isolation - Fault isolation will be accomplished primarily through comparison of the operating system performance parameters with predetermined limits and by combinatorial analysis of input/output measurements and related functions. Redundant element substitution will also be utilized where applicable.

5.1.1.3.2 Redundant Element Checkout

The EC/LSS features a high degree of redundancy at both the functional and LRU levels. Functional redundancy includes separate and independent forward and aft compartment atmosphere supply and control, water management, waste management, and thermal control systems, each fully capable of supporting the 12-man crew. Crossover connections are provided between compartments to permit assemblies in either compartment to serve as spares for those in the other compartment. Lower level redundancy is provided in the form of parallel and/or series redundant storage tanks, pressure regulators, pumps, valves, filters, etc. In all cases the redundant systems/assemblies/components are isolatible by valving or switching and are capable of being operated and tested as independent elements. They therefore present no unique problems from the checkout standpoint other than the requirement that they be exercised periodically if not normally on line.

5.1.1.3.3 Integration with Data Management System

The data acquisition interface between the EC/LSS and the DMS is defined by the measurement list in Appendix I. Signal conditioning is provided by the EC/LSS to convert the measurement sensor outputs to a standardized O-20 mVdc, 0-5 Vdc, or 0-28 Vdc level. The DMS must provide the computation capability necessary to apply calibration coefficients and convert to engineering units. The DMS also provides the test control, sequencing, and fault isolation logic.

5.1.1.4 RF Communications Subsystem

The RF Communications Subsystem (RFCS) contains the receivers, transmitters, power amplifiers, transponders, modems, and antenna systems to provide radio frequency communications between the Space Station and the ground, DRSS, Shuttle, free-flying experiment modules, and EVA crewmen. The subsystem operates in the S, K_u, and VHF bands.

5.1.1.4.1 Checkout Functions

Fault detection in the RF Communications Subsystem utilizes both operational monitoring and specific functional test routines. The operational monitoring takes place continuously while the system is in use and involves both the onboard and ground crews to a great extent. Assessment of system performance is made in much the same way one "checks out" his home communications equipment such as telephone and television, i.e. by listening to or looking at the output. Such tests are somewhat gross and subjective of course, and must be augmented by functional tests which include more precise qualitative analysis of performance. These functional tests may be performed on a scheduled periodic basis or as an aid to fault isolation in the event of a malfunction. Checkout of portions of the system will also be required prior to initiation of certain operations, such as a rendezvous and docking. Functional tests generally involve the injection of calibrated test stimuli and evaluation of equipment response.

- Stimulus Generation - Checkout of the various S-band, K_u-band, and VHF receivers requires the capability to inject RF test stimuli of the appropriate frequency and modulation characteristics into the receiver front ends and measure the corresponding receiver outputs and Automatic Gain Control (AGC) levels. Testing of transmitters and of the receiver and transmitter modems requires the injection of modulating test signals of the appropriate type and format. Stimulus requirements are included in Appendix I.

- Sensing - Sensing requirements associated with the RFCS are tabulated in Appendix I.

  The 0-5 Vdc range given for the AGC, RF power, and Voltage Standing Wave Ratio (VSWR) levels are conditioned sensor output levels rather than "raw" signal ranges and reflect the selected RFCS design approach of providing integral signal conditioning at the LRU level. Similarly, the bilevel status indicator parameters represent a variety of "raw" parameters including mode selections, switch positions, presence of primary power, and presence of input and/or output modulation. The selector switch position parameters indicate the position of multiposition switch elements such as channel selectors and antenna switches. These parameters are internally encoded such that a twelve-position switch, for example, is represented in the form of a four-bit binary word.

- Signal Conditioning - The measurement signal conditioning for the RFCS is included as an integral portion of the subsystem at the "black box" or LRU level. The measurements are therefore directly compatible with the data management subsystem.

- Limit Checking - Limit checks of the continuous or random type have limited applicability in the RFCS. This is due to the fact that the majority of the significant subsystem performance parameters, such as RF output power, are meaningful only when the equipment is actually transmitting or, as in the case of receiver sensitivity (AGC) measurements, when a calibrated input signal is present. Limit testing opportunities are therefore largely confined to periodic test situations where the necessary conditions can be established.

- Trend Analysis - Application of trend analysis techniques to selected RFCS measurements is potentially useful in detecting degradation and impending failures in such equipment as transmitters and receivers. In particular, the RF power output and VSWR of the transmitters and the AGC level of the receivers are good performance indicators and are amenable to such analysis. Care must be exercised, however, to assure proper correlation between these measurements and the various factors which influence them. Meaningful receiver sensitivity data, for example, is highly dependent upon accurate calibration of the input test signal. The maintenance of sufficiently accurate calibration of test stimuli and measurement equipment over a long term orbital mission is a problem not previously encountered in the space program and will require careful consideration.

5.1.1.4.2 Redundant Element Checkout

Redundancy in the RFCS is in the form of functional redundancy, as typified by the capability to communicate with the ground either directly or via DRSS, and in duality of systems as in the case of the dual antenna systems. These dual or functionally overlapping areas of equipment are independent of each other, however, and therefore do not constitute redundancy in the normal switchable or parallel equipment sense. As such, no unique checkout problems exist.

5.1.1.4.3 Integration with Data Management Subsystem

Stimulus requirements for the RFCS include modulated S-band, K_u-band, and VHF RF signals, analog signals, and digital inputs. The RF signals in particular are relatively complex and are unique to the subsystem. These are therefore generated by equipment internal to the subsystem. The control of these signals is a function of the DMS. The various analog signals (i.e. audio, video, etc.) required for modulation testing are likewise generated internally under DMS control. Digital test inputs required for checkout of the PM modems and exciters are supplied directly by the DMS via the data bus.

Measurement sensors and signal conditioning for the Communications Subsystem are provided as an integral part of that subsystem. The signal interface between the RFCS and the DMS is in the form of standard 0-5 Vdc signals for each measurement.

5.1.1.5 Structures

The Structures Subsystem consists of the basic Space Station structure (shell, bulkheads, etc.) and the associated equipment such as meteoroid shields, hatches, air locks, docking systems, antenna booms, and artificial gravity systems.

5.1.1.5.1 Checkout Functions

Checkout functions associated with the Structures Subsystem are relatively few and simple. These are primarily related to the verification of compartment integrity, hatch and docking port status, and to the deployment of the high gain antennas and artificial gravity systems. The checkout task is characterized by low measurement data rates, absence of special test stimulus requirements, and by comparatively uncomplicated computation requirements.

- Stimulus Generation - No stimuli, other than normal operational control signals, are required for checkout of the Structures Subsystem. Operational control requirements, as tabulated in Appendix I, consist of discrete commands for seal pressurization and similar functions.

- Sensing - Sensing requirements of the Structures Subsystem are almost entirely limited to measurement of mechanical parameters, such as door, latch and actuator position and to the measurement of gas pressure in compartments, seals, and associated tankage. These requirements are listed in Appendix I.

- Signal Conditioning - A minimum of special signal conditioning is required since many of the measurements, particularly the position measurements, are implemented in a manner (i.e., with limit switches) which is directly compatible with the Data Acquisition System. Conditioning may be required for the pressure transducers, depending upon the type selected, and for the rotational sensor. Such conditioning, where required, performs conversion and scaling of the sensor outputs and provides a standard 0-5 Vdc output to the Data Management System.

- Limit Checking - Periodic or continuous limit checking is required for selected pressure parameters, including seal pressures, compartment and airlock pressures, and docking ring compression strut pressures.

- Trend Analysis - Analysis of the Structures Subsystem has revealed no potential application of long term trend analysis techniques. Short term analysis of compartment and seal pressures is required, however, to verify pressure integrity and to detect and isolate meteoroid punctures and other leaks.

5.1.1.5.2 Redundant Element Checkout

Redundancy in the Structures Subsystem takes the form of installed and independently active elements. A typical example is the dual seals on all pressure hatches. These redundant elements, being fully operational rather than of a standby nature and being independently instrumented and controlled, require no special treatment from the checkout standpoint.

5.1.1.5.3 Integration with Data Management Subsystem

The checkout interface between the Structures Subsystem and the DMS consists of the measurement parameters listed in Appendix I. All measurements at the interface are in the form of normalized 0-5 Vdc signals and are directly compatible with the Remote Data Acquisition Units. Test sequencing and control are provided by the DMS, as is operational control.

5.1.1.6 Electrical Power Subsystem

The Electrical Power Subsystem (EPS) consists of dual isotope/Brayton power conversion elements and a power control and distribution network. The power conversion elements include the isotope heat sources and aeroshells, heat exchangers, turbines, compressors, alternators, and Gas Management Systems. The control and distribution network consists of transformer/rectifier assemblies, voltage regulators, static sine wave and square wave inverters, batteries, battery chargers, and circuit protection and switching devices.

5.1.1.6.1 Checkout Functions

The EPS encompasses a wide variety of equipment including electrical, electronic, mechanical, and fluid systems. This results in a diversity of checkout requirements as identified in the following sections.

- Stimulus Generation - Stimulus generation requirements imposed by the EPS, except for control and switching purposes, are relatively few and simple. These consist of simulated current unbalance inputs required to periodically test the operation of differential protection relays, simulated reverse current inputs to periodically test reverse current sensors, and simulated phase unbalance (open phase) signals to test phase balance protection circuits. These stimuli may take the form of fixed value currents or voltages, depending upon the final design of the protection circuitry.

- Sensing - Sensing requirements imposed by the EPS are listed in Appendix I. Measurement sensor and transducer requirements are generally well within current instrumentation capabilities. Sensor outputs are directly measurable as a dc voltage within specified ranges, or are converted to standard measurement voltages by appropriate signal conditioning circuitry.

Selected sensors are implemented redundantly due to the criticality of the measurement or to the difficulty of replacing a failed unit. Critical parameters with redundant instrumentation include heat source temperature, compressor inlet temperature, compressor discharge pressure, turbine inlet temperature, bearing cavity pressures, and turbine speed. These redundant sensors provide the opportunity to perform cross correlation and calibration of measurements.

- Signal Conditioning - Signal conditioning is required for all sensor outputs which do not fall within the standard measurement capability of the Remote Data Acquisition Units. The requirements include strain gauge temperature probe conditioning networks, ac-to-dc converters, and frequency-to-dc converters. These devices perform signal conversion and scaling as necessary to provide a standard output to the Data Acquisition System.

- Limit Checking - Limit checking routines are used to verify that critical parameters such as the isotope heat source temperatures, compressor temperature and pressures, turbine temperatures and speeds, and bearing cavity pressure remain within tolerance. Limit tests are utilized within the Power Distribution System to monitor bus currents and voltages and to monitor the states of automatic circuit protection devices such as circuit breakers and phase balance protection relays.

- Trend Analysis - Opportunities to apply trend analysis techniques to the EPS are limited. Meaningful trend data may be obtained from selected temperature measurements in the isotope heat source and in certain equipment items. The latter include bearing temperatures in the rotating machinery, and heat sink temperatures in equipment such as voltage regulators and inverters. These are relatively short-term trend parameters and may provide indications of degradation or incipient failure. Longer term trend parameters include heat exchanger and radiator inlet/outlet temperatures and flow rates which may be used to identify and project efficiency degradation in these systems.

- Fault Isolation - Fault isolation is accomplished through comparison of measured operating conditions with predetermined limits and by combinatorial analysis of input/output measurements and associated performance parameters. Redundant element substitution is also used where available.

5.1.1.6.2 Redundant Element Checkout

Redundant elements in the EPS include critical protection and switching devices, transformer/rectifier units, voltage regulators, 400-Hz square wave inverter, 60-Hz and 400-Hz sine wave inverters, 600-Hz motor/generator, batteries, and battery chargers. These are isolatible by switching. Checkout of the redundant units is accomplished by switching them on-line periodically and verifying proper functioning under normal operating conditions. A special situation exists in the case of the 600-Hz motor/generators, as both the primary and redundant units are normally used only to provide motoring start current to the Brayton cycle 1200 Hz alternator, a function normally performed only during initial activation of the Space Station. Periodic checkout of these units therefore requires a dummy load to substitute for the alternator and permit testing to be performed without interrupting alternator operation.

The inverters also present a special case. These units are not designed for parallel operation. A redundant off-line unit cannot be rotated on line without first interrupting the ac loads. To avoid this, a dummy load is provided for checkout of redundant inverters.

5.1.1.6.3 Integration with Data Management Subsystem

Stimulus requirements in the EPS involve primarily fixed value currents or voltages associated with testing of circuit protection devices. These devices are distributed throughout the Space Station rather than being concentrated, and the devices themselves are generally relatively simple. This combination of conditions favors external rather than built-in stimulus generation. A requirement is therefore imposed on the DMS to generate these stimuli and to control their application to the appropriate EPS test points.

Measurement sensors, transducers, and signal conditioning for the EPS are provided as an integral part of that subsystem. The signal interface between the EPS and the DMS is in the form of a DC voltage for each measurement. The voltage levels are in the ranges of 0.20 mV, 0-5 V, and 0-28 V.

5.1.1.7 Data Management Subsystem (DMS)

The testing of the DMS will involve principally a series of software programs designed to exercise the DMS group in a normal subsystem configuration. If there is a failure in one of the units, the OCS must isolate the failure, reconfigure the DMS Subsystem to restore normal operation, alert the crew of the failure and its location, and record the event. Given that a unit has been replaced, the OCS must maintain knowledge of the operational status of the new unit.

Within the DMS, each functional unit must be tested. This means that there must be at least CPU type tests, main store tests, bulk memory tests, bus controller tests, etc. Since there exists more than one path to perform certain functions in the subsystem configuration, it is important to verify that intercommunications among units also exists. This requirement gives rise to interface tests. Some of the interfaces which exist include CPU-to-CPU, CPU to both main and bulk memories, CPU to primary and secondary bus controllers, bus controllers to terminals, terminals and RDAUs, and RDAUs to individual subsystems. The fact that the many communication paths are possible generates the requirement that a path must be switchable or alterable to restore operation. Determining which path must be altered indicates that a fault isolation capability also must exist. Fault isolation may occur by commanding tests to various equipment in a sequence such that the analysis of the pattern of responses logically leads to a faulty piece of equipment. The maintenance of continuous knowledge of the operational status of the equipment can be translated into the requirement to maintain a subsystem status table (or configuration table) in software. If the operator is to be involved in any actions, interactive crew/display/software tests are required.

5.1.1.7.1 DMS Test Methods

The DMS checkout will consist principally of software diagnostics supplemented with additional temperature, voltage, and logic measurements.

- Central Processing Units - Error detection and isolation in the central processing units depend on diagnostic software. In the multiprocessing configuration, one central processor can be utilized to check another central processor. This can be accomplished through memory or through a direct interface. In addition, parity checking can be implemented between interfaces of the central processor with other units.

- Main Store Units - The main store units can be checked periodically by attempting to address all locations in each unit, performing ripple tests, sum checks, etc. BITE capabilities in the form of parity checking will occur on data read from storage and data presented by the central processors. Parity checking will be the principal means of error detection.

- Data Bus Controller - The data bus controller is the communication path between memory and central processor and the data bus. Verifying operation of the controller can be implemented by software diagnostics. BITE hardware can be incorporated, which upon command from the CPU, inserts a known serial data word (pattern) into the input side of the controller and transmits the word back to the CPU. The CPU can compare the response to the command word.

- Digital Data Terminals - The digital data terminal interfaces the various subsystems/experiments and the data bus. The terminal can be tested much like the bus controllers. A self-check feature in the form of BITE can be added which routes calibrated signals through the unit to the CPU (via the data bus) for verification.

- RDAU - The RDAU can be tested in the same manner as the bus controllers and data terminals. The RDAU contains 32 analog inputs and 32 digital inputs. One input of each type can be reserved to wrap around an analog or digital signal into the input for return to the CPU. The CPU would command the test voltage or signal and examine the response for known conditions.

- Local Monitor and Display Unit (LMDU) - The LMDU electronics will be checked in an identical manner to the RDAU. The displays will require crew participation.

- Command and Display Consoles - The controls and displays associated with the consoles are subjected to a form of continuous test through normal use. For the displays, standard test patterns containing all the symbols and numerics presented to the crew will verify operation of display and symbol generation. The controls are exercised through the normal equipment utilization.

- Image Processing - Tests for the image processing equipment will consist primarily of supply voltage and analog measurements for which an interface via an RDAU should be provided to the DMS computer. Optical equipment is tested through normal use. Integral diagnostics should be included with the special purpose processors such that the diagnostics can be commanded from the DMS computer.

- Bulk Storage - The basic operation of bulk memory can be verified by writing-reading random length records of predefined data patterns and checking the response for correctness. The basic capabilities of writing, sensing, reading forward and backward, I/O test, and control will be verified via this technique. Error detection through parity checking also will be performed throughout the test.

- GN&C Preprocessor - Built-in test equipment is assumed to be applicable. Since the preprocessors are not yet defined, the form of BITE is yet to be determined.

- <u>OCS Measurements</u> - In addition to the software diagnostics and BITE provisions which can be incorporated into the OCS, a series of measurements must be made on certain equipment. Some of the units may be temperature sensitive, which will generate a requirement to monitor the temperature. Most of the units also will contain an integral power supply or converter which must be monitored. There also may be certain logic which must be monitored.

  The measurements which are required fall into three categories. These include:

  a. Analog

  b. Digital/discrete

  c. Visual

The analog measurements will consist primarily of temperature and power supply voltages. The digital or discrete signals will be checked through software analysis of state or patterns. Visual inspections could be a visual analysis of a display, a pulse train or pulse shape - visual inspection may be more appropriate in performing adjustments, but it represents a form of measurement which may be required.

5.1.1.7.2 OCS Computer Program Segments

The operational and maintenance requirements indicate that two levels of testing or test control are required. Depending on the type of test being exercised, different information will be extracted and different actions will result from the testing. Two major sets of computer programs have been identified to perform this testing. Within each program there are several modules required to extract the desired information. The two test levels identified which translate into computer programs include:

- Continuous orbital monitoring (COM)
- Subsystem Fault Isolation (SFI)

The continuous orbital monitoring program is required to maintain cognizance of equipment's operational status at all times and to isolate failures in order to reconfigure the equipment. The continuous monitoring program can be hardware or software. The hardware can consist of Caution and Warning or of a machine check interrupt from parity error or power transients. The software program would consist of a set of test programs performed iteratively and concurrently with the application programs. The test programs would be interleaved with the application programs, and performed at a rate determined by the executive. The subsystem fault isolation program would be designed to perform more extensive testing than would be performed in the "continuous" program.

5.1.1.7.3 Test Program Modules

Each of the two major program sets will contain several modules to perform specified functions. These are discussed in the following paragraphs.

5.1.1.7.3.1 Continuous Orbital Monitoring Program Modules

The continuous orbital monitoring modules will consist of the DMS test programs (e.g., CPU, memory addressing, I/O operation, etc.), the polling of test points, and a Caution and Warning module.

- Test Program Modules - The test programs are designed to verify operation of individual configurable elements. The rationale for this is to maintain continuous configuration control, necessitating periodic information regarding the operational status of all configurable elements comprising the DMS group. These test modules will be designed to exercise as much of each LRU as possible in the allocated time. The modules will confirm, for example, fundamental operations of the CPUs, main memory, bus control, terminals, etc.

- Test Point Polling - The test point polling module is required to sample voltages, temperatures, and logic patterns for out-of-tolerance conditions or pattern errors. The test points can be handled singly or in blocks.

- Caution and Warning - A Caution and Warning module is required to monitor critical signals on a continuous basis. This module may be implemented through selective parts of the two modules above; i.e., through execution of selective diagnostics or through the polling of selective test points.

5.1.1.7.3.2 Subsystem Fault Isolation Modules

Listed below are candidate program modules which would comprise the Subsystem Fault Isolation program. These change with regard to the number of modules or because of a merging of responsibilities. The list includes:

(1) Failure verification/isolation modules

(2) Failure event analysis module

(3) Reconfiguration module

(4) Subsystem status table

(5) Display/Record/Telemetering Module

(6) Repair verification modules

- Fault Verification/Isolation Modules - Failure verification/isolation modules are designed to resolve failures to the level at which redundancy is applied (for reconfiguration purposes) and to the LRU level to support the on-line remove-and-replace maintenance philosophy. Subsequent to the detection of an error, anomaly, or failure, it may be necessary to verify via an independent path, that an event has occurred or that a particular path is disabled. This may be accomplished by performing a separate routine or by correlating results from other routines. The isolation modules will be executed in whatever sequence is necessary to resolve the failure to a reconfigurable path.

- Failure Event Analysis Module - Failure event analysis modules are designed to evaluate the event in terms of criticality, failure history, active/inactive status, etc. Based on an FMEA, hazards studies, etc., failures can be classified into certain groupings; e.g., critical items, time critical items, items involving crew actions, items automatically switched through internal BITE, etc. When an event occurs, it is necessary to evaluate the source of the event (whether OCS or LRE BITE), the criticality of the function lost and whether the crew must be involved in any subsequent actions, the redundant paths available and their status with regard to power on/off, failure history, etc.

- Reconfiguration Modules - Reconfiguration modules are designed to initiate and execute the sequence of operations necessary to reconfigure the subsystem. Depending on the source of the failure, different procedures may be involved in reconfiguring the equipment. The reconfiguration can occur in software or it can be a physical switching of redundant paths. These modules will be required to execute the unique actions associated with each LRU, path, function, or subsystem.

- Subsystem Status Table - The subsystem status table is designed to maintain the status of all DMS reconfigurable elements. To prevent the switching or reconfiguring of faulty equipment, it is necessary to maintain a subsystem status table of all equipment. In the event of a failure, the subsystem status table must be analyzed with respect to the failed element to determine if a redundant path is available. Subsequent to the remove-and-replace of the faulty LRU and the successful completion of an LRU test module, the subsystem status table would be updated.

- Display/Record - Display/record is designed to provide interactive display/control with the crew and to provide an event history file. In order to provide prompting information and to provide interactive capabilities between OCS and crew, display formats (or messages) containing such information will be required. In addition, an event history should be maintained for ground processing and analysis (logistics, provisioning, long term trend data, etc). The capability for telemetering any or all test data also will require certain provisions.

- Repair Verification/Adjustment - The repair verification/adjustment is designed to verify proper operation of LRUs subsequent to repair. Special repair verification or adjustment modules may be required to re-verify an LRU or to perform LRU adjustments. These tests may not be as extensive as the failure verification/isolation modules, but could contain certain segments of the diagnostic modules.

5.1.1.7.4 Computer Program Top Level Flow

The Multiprocessor Executive System must provide certain times, on a scheduled basis, during which DMS tests can be performed. The executive may or may not subdivide the DMS tests depending on computer load at the time or on the duration required to perform certain test sequences. Subsequent to DMS tests, the experiment module tests or particular subsystem tests can be performed. At specified intervals, the executive must return to the regular application programs.

If during the DMS tests, a failure is detected, it must be resolved or isolated to an LRU or to a data path that is reconfigurable. The output of the LRU and interface tests is a system reconfiguration, display message to the crew, a recording of the event, and an update of the subsystem status table.

5.1.1.7.5 DMS Redundant Element Checkout Techniques

The control of redundancy within the DMS will be a software function principally and can be implemented through the LRU diagnostics within the Subsystem Fault Isolation Program. The redundancy control function consists of detecting errors or failures and isolation of the failure to a reconfigurable path. The general case of redundancy control is considered initially.

An output from a single function is acquired by one of two RDAUs (one designated as "prime" and the other as "secondary"). The RDAU will perform some processing to the function and feed the information to its respective digital data terminal. From the terminals, the data is fed to the computer via one of two data bus controllers (again, one is designated as "prime" and one "secondary"). Control of redundancy within the computer will depend on diagnostic software. Individual CPU diagnostics can be performed and cross checking of one CPU by the other CPU is possible. Cross checks can be implemented through check words in memory or through a direct control interface. If one CPU is determined to be at fault, the other CPU can assume the load. With regard to memory, each main store unit can be checked periodically by diagnostic software. BITE in the form of parity checking will play a significant role in error detection and isolation on data read from memory to the CPU or to the data bus controller.

The control of redundancy in the data acquisition path can be implemented by the incorporation of BITE within data acquisition elements and through software. Figure 5-1 shows a method of isolating and reconfiguring the data acquisition elements. If an out-of-tolerance event or failure indication occurs, it can be true or it can be a false alarm. By performing an RDAU test, the RDAU can be absolved of the responsibility or determined to be the source of the problem. If the RDAU is faulty, the data point has an alternate path through the secondary RDAU. If after performing the RDAU test (which indicated failure) the same indication prevails through the secondary RDAU, the failure is between the RDAU and the CPU. By alternately addressing data acquisition test command between primary and secondary elements, a logical isolation and reconfiguration pattern can be developed (as shown in Figure 5-1). This procedure would isolate to a replaceable unit.

Redundancy at the RDAU/sensor level for the baseline has three configurations. The most critical signals (warning signals) have duplicate sensors and two independent paths to the data bus. The next level signals (caution signals) also have duplicate sensors and two paths to the data bus, but these paths are somewhat different from those for the warning signals. The third level of signals has a single sensor source, but has two separate RDAU paths to the OCS processors. The redundant sensors and redundant paths afford point-to-point correlation of data in the case of anomalies. In the case of warning signals, the data is fed to the CCDC and data bus through an LMDU and to the bus through an RDAU

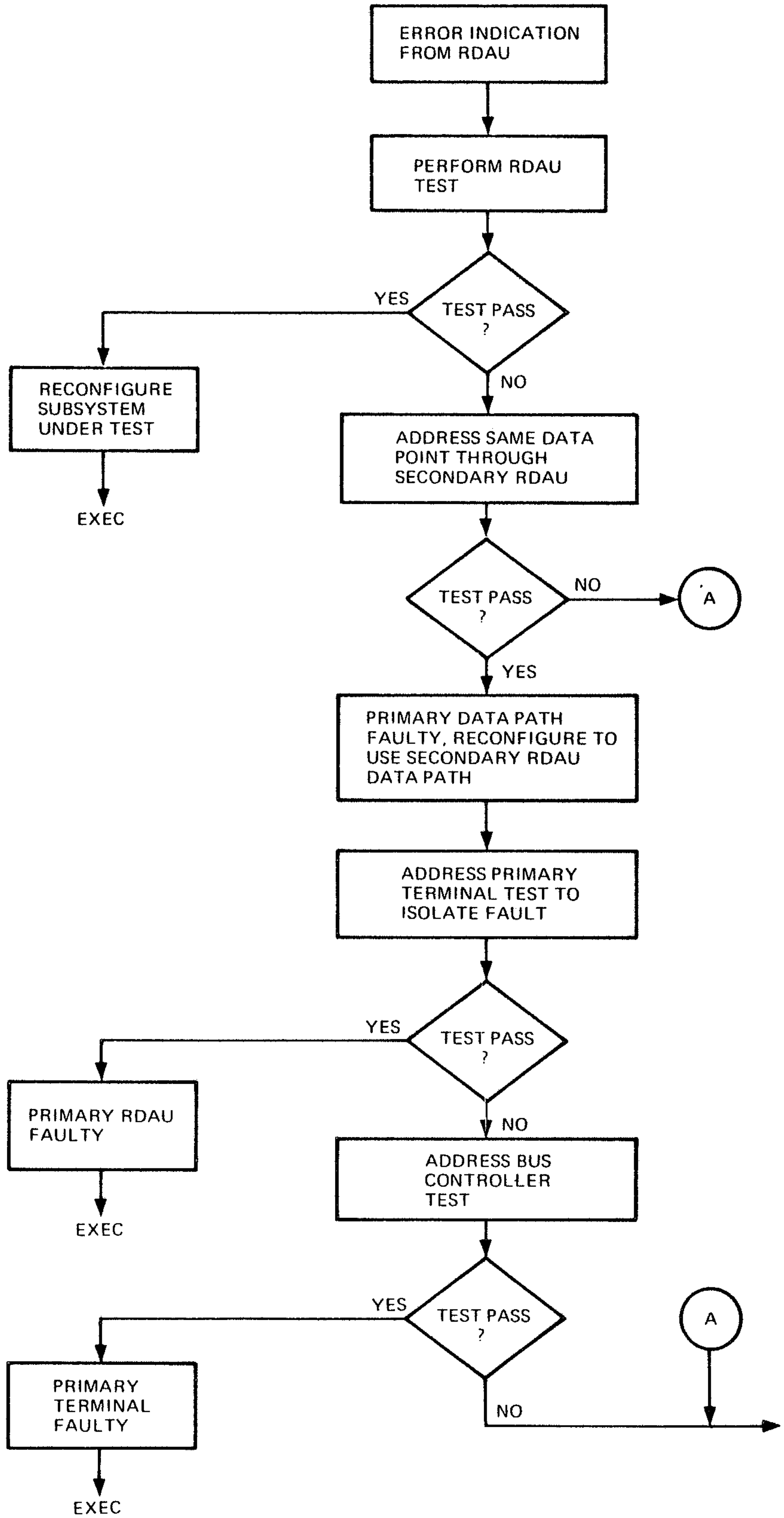

Figure 5-1. Data Acquisition Configuration Control

and terminal. If an out-of-tolerance indication exists, it is possible to address the alternate source and verify the condition. This technique also makes heavy use of software for configuration control.

5.2 INTEGRATED CHECKOUT STRATEGY

This analysis identifies the integrated checkout functions associated with Space Station subsystems during the manned orbital phase of the mission. These functions are depicted in Figure 5-2 and are those required to ensure overall availability of the Space Station. Characteristic of integrated testing is the fact that the test involves subsystem interfaces, and, therefore, test objectives are associated with more than one subsystem.

5.2.1 INTEGRATED STRATEGY

Six checkout functions have been identified:

- Caution and warning
- Fault detection
- Trend analysis
- Operational status
- Periodic checkout
- Fault isolation

These functions represent a checkout strategy of continuous monitoring and periodic testing with eventual fault isolation to a line replaceable unit (LRU). Under this aspect the functions are grouped as -

CONTINUOUS MONITORING	PERIODIC TESTING	FAULT ISOLATION
• Caution and warning	• Automatic tests	• Localize to SS
• Fault detection	• Operational Verification	• Isolate to RLU
• Trend analysis		
• Operational status		

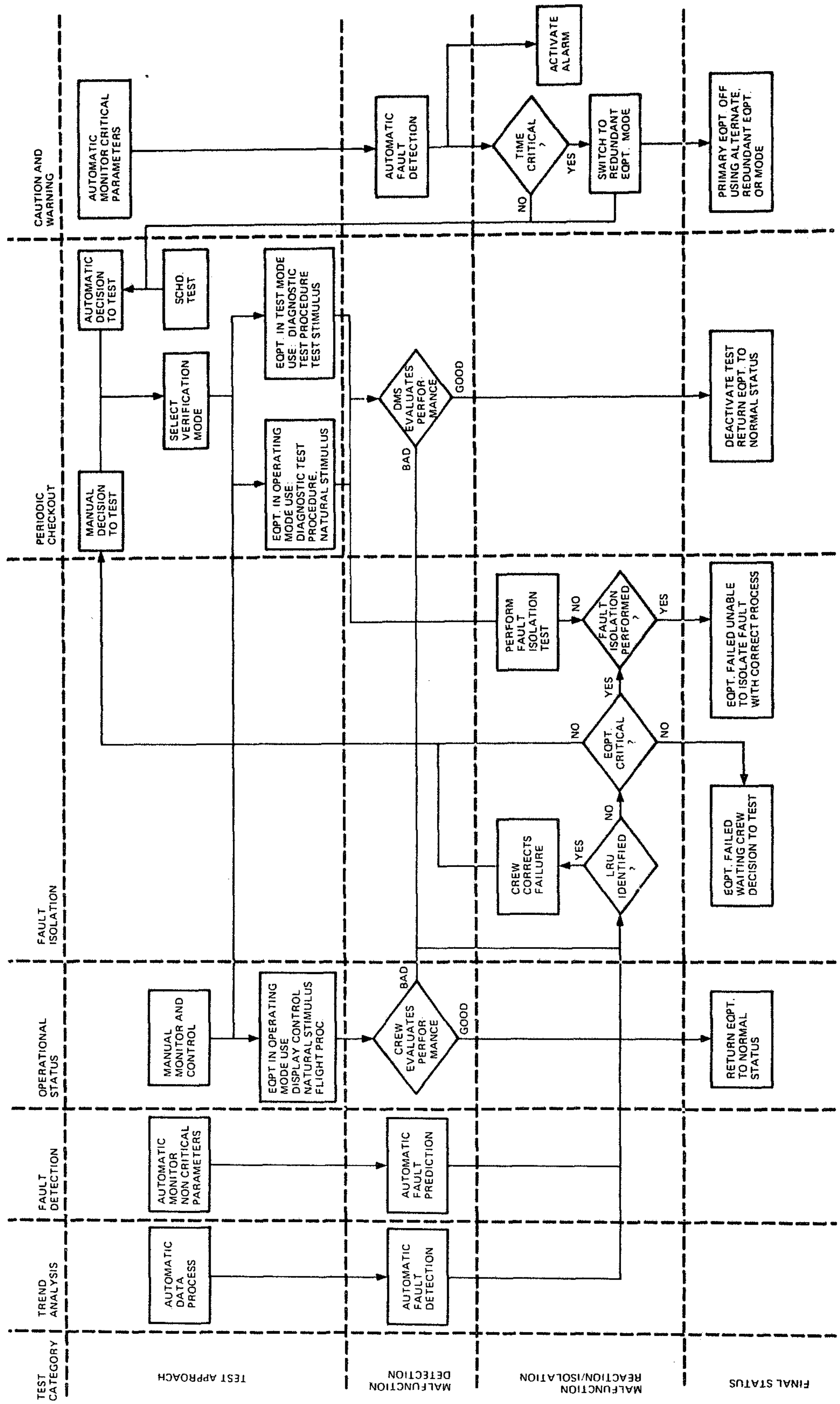

Figure 5-2. Integrated Checkout Functional Flow

General characteristics of these groups are defined below:

5.2.1.1 Continuous Monitoring

Continuous monitoring is not a test per se. It is a concept of continuously sampling and evaluating subsystem parameters for in/out-of-tolerance conditions. This evaluation does not necessarily confirm that the subsystems have failed or are operating properly. The evaluation is only indicative of the general status of the subsystems. For example, a condition exists where the integrated subsystems are indicating in-limit conditions, but during the next series of attitude control commands, an error in Space Station position is sensed and displayed. Since three subsystems, DMS, GN&C, and P/RCS, are involved in generating and controlling the Space Station attitude, a "positional error" malfunction is not directly related to a subsystem malfunction. The malfunction indication is only indicative of an out-of-tolerance condition of an integrated function. Final resolution of the problem to a subsystem and eventually to LRU will require diagnostic test-procedures that are separate from the continuous monitoring function.

There are situations in which the parameters being monitored are intended to be directly indicative of the condition of a subsystem or an LRU. Examples of these include tank pressures, bearing temperatures, and power source voltages. However, even in these simpler cases when a malfunction is detected, an integrated evaluation will be performed to ascertain that external control functions, transducers, signal conditioning, and the DMS functions of data acquisition, transmission, and computation are performing properly. This evaluation will result in either a substantiation of the malfunction or identification of a problem external to the parameter being monitored.

Figure 5-2 shows the logic associated with each function in the continuous monitoring group, as well as the integrated relationships between these and the total checkout functions. The caution/warning and fault detection functions are alike in their automatic test and malfunction detection approaches, but are different in terms of parameter criticality and malfunction reaction. The caution/warning function monitors parameters that are indicative of conditions critical to crew or equipment safety. Parameters not meeting this criticality criteria are handled as fault detection functions. Figure 5-2 shows that in the event of a critical malfunction, automatic action is initiated to warn the crew and sequence the subsystems to a safe condition. Before this automatic action is taken, the subsystems must be evaluated to ascertain that the failure indication is not a false alarm and that the corrective action can be implemented. After the action is taken, the subsystems must be evaluated to determine that proper crew safety conditions exist. Since automatic failure detection and switching can be integral to subsystem design (self-contained correction) and subsystems can be controlled by the operational software or manual controls, it is imperative that the status of these events be maintained and that the fault detection and correction software be interfaced with the prime controlling software. For malfunctions that are not critical, the crew is notified of their occurrence, but any subsequent action is initiated manually.

The next continuous monitoring function, trend analysis, automatically acquires data and analyzes the historical pattern to determine signal drift and the need for unscheduled calibration. It also predicts faults and indicates the need for diagnostic and fault isolation activities. An example of a parameter in this category is the partial pressure of nitrogen. Nitrogen is used to establish the proper total pressure of the Space Station. Since it is an inert gas, the only makeup requirements are those demanded by leakage or airlock operation. The actual nitrogen flow rate is measured, and calculations are performed which make allowances for normal leakage and operational use. When these calculations indicate a trend toward more than anticipated use, the crew is automatically notified and testing is initiated to isolate the problem to the gas storage and control equipment or to an excessive leak path. The historical data is not only useful in predicting conditions but is also useful in providing trouble-shooting clues. The data might reveal, for example, that the makeup rate increased significantly after the use of an airlock. This could lead directly to verifying excessive seal leakage.

The final continuous monitor function is in operational status. This function is performed by the crew and is nonautomatic with the exception of the DMS computer programs associated with normal Space Station operational control and display functions. The concept of continuous monitoring recognized and takes advantage of the crew's presence and judgment in evaluating Space Station performance. In many instances the crew can discern between acceptable and unacceptable performance, and they can clearly recognize physically-damaged equipment or abnormal conditions.

5.2.1.2 Periodic Testing

As opposed to continuous monitoring, periodic testing is a detailed evaluation of how well the Space Station subsystems are performing. Figure 5-2 shows that periodic testing is not accomplished by any one technique. Rather, a combination of operational and automatic test approaches is employed. The actual operational use of equipment is often the best check of the performance of that equipment. Operation of Space Station equipment and use of the normal operating controls and displays will be used in detecting faults and degradation in the subsystems. This mode of testing is primarily limited to that equipment whose performance characteristics are easily discernible, such as for motors, lighting circuits, and alarm functions.

Automatic testing is performed in two basic modes:

- With the subsystems in an operating mode, the DMS executes a diagnostic test procedure which verifies that integrated Space Station functions are being properly performed under normal interface conditions in response to natural or designed stimulation. This mode of testing allows the evaluation of Space Station performance without interrupting mission operations.

- For those situations where the integrated performance or interface compatibility between subsystems cannot be determined without known references or control conditions, the DMS will execute a diagnostic procedure in a test mode. In this mode, control, reference, or bias signals will be switched in or superimposed on the subsystems to allow an exact determination of their performance or localization of problem between the interfaces. Since the test mode may temporarily inhibit normal operations, the DMS must interleave the test and operational software to maintain the Space Station in a known and safe configuration.

The scheduled automatic tests are performed to verify availability or proper operation of "on-line" subsystems, redundant equipment, and alternate modes.

- Periodic Verification of "On-Line" Subsystems - The first checkout requirement is a periodic verification that on-line subsystems are operating within acceptable performance margins. The acceptable criteria for this evaluation is based on subsystem parameter limits and characteristics exhibited during Space Station factory acceptance or pre-flight testing. The rejection criteria and subsequent decision to repair or reconfigure subsystems is based on the criticality of the failure mode. If the subsystems appear to be operating properly, but the test clearly indicates an out-of-tolerance condition, then one of the following alternatives must be implemented:

    - If the failure mode is critical, the crew normally takes immediate action to isolate and clear the problem.

    - If the failure mode is not critical, the crew can take immediate action, schedule the work at a later time, or wait until the condition degrades to an unacceptable level.

- Redundant Equipment Verification - A second checkout requirement is verifying that standby, off-line, or redundant equipment and associated control and switching mechanisms are operable. The acceptable/rejection criteria for these evaluations is identical to those for normally operating equipment. A primary distinction of this function is that equipment may have known failures from previous usage or tests. This situation occurs when the crew has knowledge of a failure but has not elected to perform the necessary corrective action. The checkout function then becomes one of equipment status accounting and maintenance/repair scheduling. The status information is interlocked with mission procedures and software to preclude activation of failed units while they are being repaired or until proper operation following repair is verified.

- Alternate Mode Verification - The third checkout function is verifying the availability of alternate modes of operation. This function is essentially a confidence check of the compatibility of subsystems'interaction and performance during and after a change in the operating mode. To some extent this function overlaps with redundant equipment verification, but is broader in scope in that it verifies other system-operating characteristics. For example, some modes will involve manual override or control of automatic functions or automatic power-down sequences.

5.2.1.3 Fault Isolation

Fault isolation to an LRU is a Space Station goal. As shown in Figure 5-2, fault isolation testing is initiated when malfunction indications cannot be directly related to a failed LRU. The integrated test functions associated with fault isolation are localizing a malfunction to a subsystem or to an explicit interface between two subsystems and identifying the subroutine test necessary for LRU isolation. In structuring this relationship between integrated subsystem tests for fault localization and subroutine tests for fault isolation, the DMS, in conjunction with the test procedure documentation, must establish an effective man-machine interface so that in the event of an unsolved malfunction the crew will be able to help evaluate the condition and determine other test sequences necessary to isolate the problem. To accomplish this requirement, the DMS must be capable of displaying test parameters and instructions in engineering units and language and be capable of referencing these outputs to applicable documentation or programs that correlate test results to corrective action required by the crew.

Section 6

ONBOARD CHECKOUT TEST DEFINITIONS

6.1 SUBSYSTEM TEST DEFINITIONS

The on-orbit tests required to insure the availability of the Space Station subsystems are defined herein. Also delineated are the measurement and stimulus parameters required to perform these tests. Two discrete levels of testing are defined, i.e., continuous status monitoring tests for fault detection of critical and noncritical parameters, and subsystem fault isolation tests for localization of faults to a specific Line Replaceable Unit. In addition to these two levels, tests are defined for periodic checkout and calibration of certain units, and parameters requiring analysis of trends are defined.

Due to the software module approach to DMS checkout, it was deemed necessary to estimate the CPU time and memory required to implement these modules along with an assessment of the services required from an Executive Software System to control the checkout.

These test descriptions, measurement, and stimulus information provided for each subsystem, and the software sizing information provided for the Data Management System provide the data required to estimate the checkout impact on the DMS software and hardware. Table 6-1 is a summary of the measurement and stimulus requirements for the Space Station.

6.1.1 GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

The GN&C Subsystem operates in a closed-loop mode with the Data Management and Propulsion Subsystems as elements of the loop. Normal operation is fully autonomous. Station attitude, position, and rate information are derived by the DMS from the GN&C sensors such as star trackers, horizon sensors, gyros, and accelerometers. Reaction controls are then computed by the DMS and transmitted to the propulsion thrusters. GN&C operation is thus closely integrated with both of these other subsystems. Operation is also influenced to a high degree by external factors such as shifts in vehicle mass, drag, and center of gravity and by disturbances such as docking impacts. These factors must be accounted for in performing checkout and fault isolation tasks.

Table 6-1. Measurement/Stimulus Summary

SUBSYSTEM	STIMULUS					RESPONSE			STATUS MONITORING								
	Analog	Bilevel	Digital	Pulse	RF	Analog	Bilevel	Digital	Total	Non-Critical	Caution	Warning	Periodic Checkout	Cali-bration	Trend	Fault Isola-tion	Remarks
Guidance, Navigation and Control	20	145	62	6		127	161	70	692	130	16		516	74	74	592	
Propulsion-Low Thrust		134				120	124		378	152	14		378	48	8	378	
Propulsion-High Thrust		126/62				287/117	123/63		536/242	80/28	33/15	14/10	536/242	259/111	117/43	482/222	Arc-g/Zero-a periods
Environmental Control/ Life Support	12	111				683	294		1100	147	209	32	1100		135	1100	172 Caution/Warning Signals are for IVA/EVA
RF Communications	37	206	36		77	131	286	28	801	58			576	24	93	801	
Structures	13/11	115/13				49/42	69/50		196/126	7			103/84			146/126	
Electrical Power-ICD	71	367				523	454		1415	520	18		993		143	1415	
Electrical Power-I/BR	6	2				132	48		188	2	28	8	32		17	176	
Data Management			53			33	188	83	357	357			62	62	62	357	
Total	157/155	1107/ 1041	151	6	77	2085/ 1908	1747/ 1678	181	5511/ 5299	1755/ 1401	318/300	54/50	4296/ 3983	467/319	549/575	5415/ 5165	

6.1.1.1 Status Monitoring

Fault detection within the GN&C Subsystem is accomplished primarily by monitoring of selected performance parameters and comparing the resulting measured or computed values with predetermined limits and/or against parallel redundant parameters. The parameters to be monitored in this manner are listed in the Status Monitoring column of Appendix I-1. Precise sampling intervals are not required. Detection of an out-of-limit condition results in immediate notification of the crew. In the case of critical parameters or where otherwise deemed desirable, an automatic fault isolation routine is automatically initiated to identify the faulty LRU. Otherwise, initiation of further action is a crew option.

Fault detection procedures must be conditioned where necessary to account for external disturbances. For example, leakage or venting from the Station will cause a response to the subsystem similar to that of a failed open reaction jet. A change in the Station configuration, such as that due to docking or undocking of experiment or crew cargo modules will result in subsystem performance perturbations which can be interpreted as faults unless these events are accounted for in the subsystem logic.

Sixteen caution functions have been identified for the GN&C Subsystem. These are the bearing temperature and vibration monitors for the CMGs.

6.1.1.2 Trend Analysis

Certain of the GN&C performance parameters are amenable to trend analysis for detection of degradation or pending failure. These are identified in Appendix I-1 in the Trend column. Included are gyro and accelerometer temperatures, laser transmitter power and CMG spin rate, temperature, and vibration. Trend data of another type is required on the frequency and duration of high thrust reaction jet firing. This data is necessary to determine actual versus scheduled energy requirements and fuel consumption.

6.1.1.3 Periodic Checkout and Calibration

Since most GN&C faults are detectable by operational monitoring, periodic checks are performed primarily to ascertain that qualitative performance parameter degradations which are not obviously detectable have not occurred, and to detect failures in inactive or standby equipment. Calibration is a subtask of the periodic checkout and will be conducted during the periodic event. Checkout intervals are nominally once per month based on predicted performances of the components. The horizon detectors for artificial-g operation, star trackers for inertial orientation, and rendezvous and docking trackers are used infrequently and will require function testing prior to the respective events. The automatic landmark tracker, which is a new flight item, is checked once per week for the first year when it is being flight tested. After the first year, it is checked once per month as is the rest of the subsystem.

Checkout utilizes preprogrammed checkout routines and employs the technique of introducing calibrated stimuli at the first practical point in the forward path of the GN&C loop and monitoring subsequent downstream points for checks and calibration. Most of the downstream monitoring points are operational data interfaces with the DMS and DMS-computed data, such as attitude or position errors. The test sequence therfore begins with verification, through self-diagnostic routines, of the DMS software and DMS/GN&C interfaces. This is followed by verification of the sensor electronics and data buffers and of the sensors themselves. The final portion of the sequence checks the reaction control elements of the subsystem, including the CMGs and the jet drivers.

6.1.1.4 Fault Isolation

All stimulus and measurement parameters are utilized for fault isolation. As indicated previously, fault detection is accomplished through direct measurement of these parameters or through DMS computations based upon these measurements. The DMS-computed fault detection is generally at the system level and is in terms of excessive attitude, position, or instrument pointing errors. The directly detected faults, such as excessive CMG bearing temperature, are generally more component or assembly oriented. In either case, the fault isolation function involves systematic analysis of the fault indicators and associated functions using the normal operating input/output relationships plus special test stimuli where necessary. Applicable portions of the periodic checkout routines are used.

Since the fault detection and isolation are limited to the LRU level, some of the more familiar component monitor parameters are omitted from the stimulus/meaurement list. An example is the spin rate monitor of the instrument gyro. This is an often monitored function in many applications but in this instance, the gyro performance is verified by the response to a command torquing signal which checks the gyro as an overall transfer function. If the response is out-of-specification, then the gyro as an LRU will be replaced regardless of whether it was the spin rate, signal generator, torquer scale factor, or any other fault which caused the deviation.

A typical test and fault isolation routine is diagrammed in Figure 6-1. This routine involves the Laser Rendezvous Tracker, which is used to acquire and track docking targets. The device transmits a coherent parallel pulsed light beam and detects energy returned from a passive reflector on the target vehicle. Course pointing of the beam is achieved by mechanical gimbals, while fine pointing is achieved by a piezoelectric beam deflector and optical deflection amplifier. The

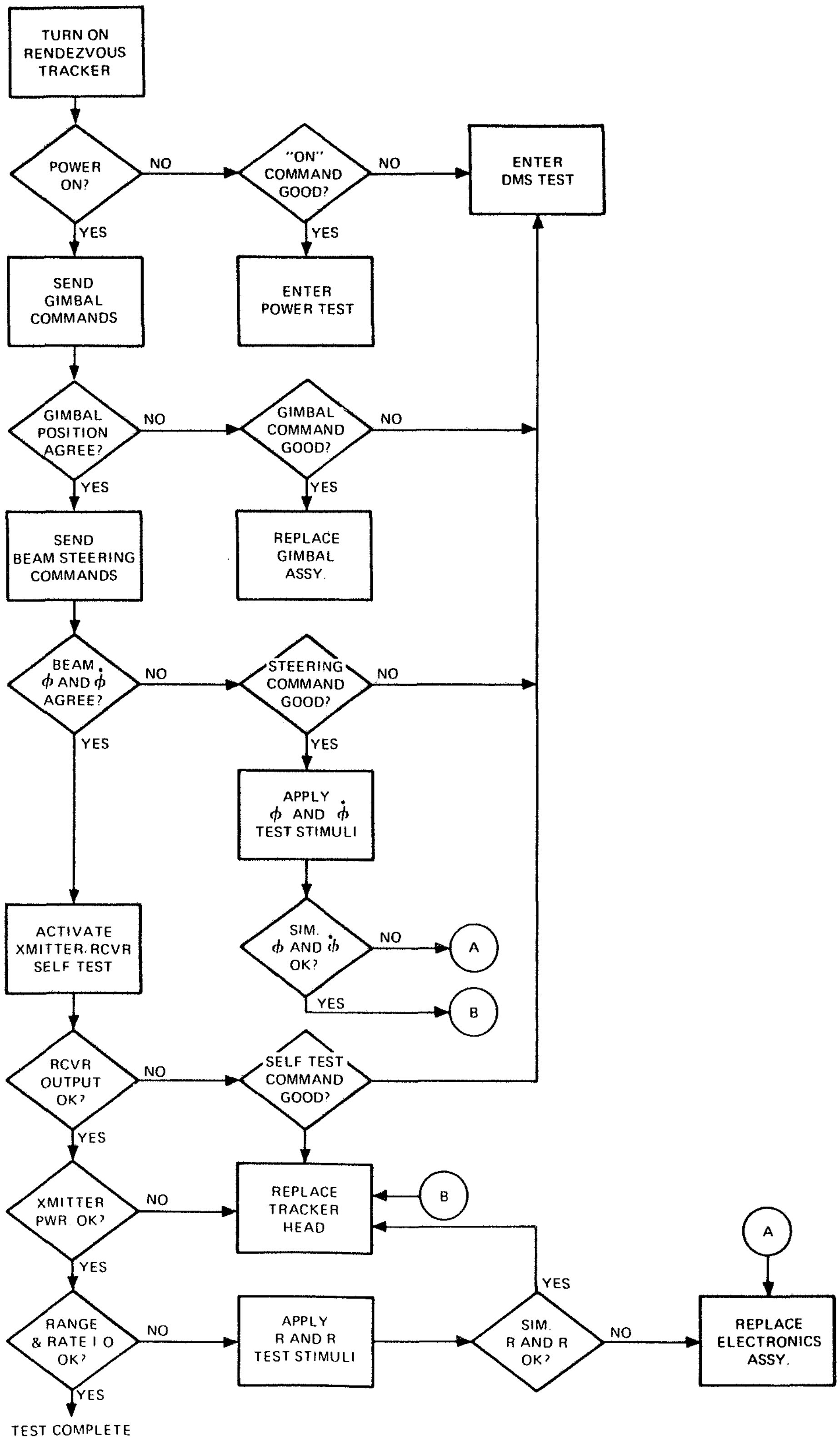

Figure 6-1. Rendezvous Tracker Test

device provides angles, range, and range rate as outputs. Three LRUs are involved, these being the tracker head, the gimbal assembly, and the electronics assembly. The tracker head includes an optical self-test mode which allows a portion of the transmitted pulse to be reflected back into the receiver.

The test sequence shown in Figure 6-1 assumes that no actual target is available. The test is therefore not 100 percent complete in that the actual beam pointing accuracy cannot be verified.

6.1.2 PROPULSION SUBSYSTEM

The Propulsion Subsystem consists of two major elements, one being the High-Thrust Monopropellant Hydrazine System and the other the Low-Thrust Resistojet Thruster System. Both systems interface with the GN&C and Data Management Subsystems for control. The Low-Thrust System also interfaces with the EC/LS Subsystem for biowaste propellants.

6.1.2.1 High-Thrust System

The High-Thrust Propulsion System must satisfy both an initial Space Station two-year artificial-gravity phase and subsequent zero-gravity phase. The quantity of subsystem measurements and stimuli required for the former are more than double the quantity required for the latter. This is due to increased propellant and pressurant tankage requirements as well as the increased number of thrusters necessary during artificial gravity operations.

Operation of the High-Thrust System is automatic with the thruster firing controlled by the GN&C Subsystem. All other normal operational controls for the subsystem are associated with tank switching, thermal control, and safing functions. The need for tank switching is monitored and controlled by the DMS, while the thermal control assemblies are controlled by various thermostats.

Although the High-Thrust System is normally required only during scheduled events such as the artificial-gravity experiment or docking, the system is continuously maintained in a pressurized and ready-to-fire state. This concept is strongly influenced by fluid characteristics, resupplying penalties, and the need for the subsystem to be available for unscheduled events or emergencies. Safety parameters as well as certain other system status and readiness indicators are therefore monitored continuously even though the system may be inactive. Scheduled high-thrust events are typically at three-month intervals and are critical in nature. A complete functional check of the system is therefore required prior to each event. Resupply operations are also scheduled every three months and require that leak and functional checks of the transfer system lines and controls be performed. During the events and particularly during actual thruster firing intervals, subsystem status monitoring requirements become extremely important. Appendix I-2 contains the measurements and stimuli required for checkout of the High-Thrust Propulsion Subsystem.

6.1.2.1.1 Status Monitoring

Continuous monitoring of high-thrust propulsion system parameters is performed to detect over-pressure conditions, out-of-tolerance regulation, major leakage, empty tankage, and thruster malfunctions:

- Overpressure - Each tank is relieved automatically through a burst disk and mechanical relief valve when a major overpressure condition arises. Tank pressure as well as relief valve actuation is monitored continuously with a signal initiated to alert the crew of any unwarranted pressure build-up.

- Out-of-Tolerance Regulation - Redundant pressure regulation is provided by parallel regulators, and automatic malfunction detection and switching is provided by pressure switches which activate the valves to each regulator. Pressure switches initiate the appropriate commands dependent on the malfunction mode (high or low regulation outlet pressure). A signal is also provided to alert the crew to any regulator switchover.

- Major Leakage - Pressure transducer signals are monitored continuously, and pressure decay rates are computed. An indication of any abnormal pressure decay requires the initiation of closing the appropriate isolation valves.

- Tank Switching/Isolation - Any pressure differential across the propellant tanks (gas ullage to fluid side) is detected and the appropriate switching commands initiated. This differential pressure occurs when a tank runs dry thus requiring the next tank (normally isolated) to be put on-line to feed propellant to the thrusters.

- Thruster Out-of-Limit Operating Pressure, Temperature, and Voltage Conditions - The thruster, to operate safely, must have specific inlet conditions. These conditions are monitored and thruster operations inhibited if they are out of limits.

6.1.2.1.2 Periodic Checkout

Daily checks of the High-Thrust System are conducted to determine its operational status. A more detailed verification is also performed approximately every three months.

Typical daily subsystem status checks are accomplished through visual monitoring of displays and through automatic limit checks and trend analysis. The following status checks are required:

- Subsystem Status - Insures that the subsystem is in an operational state (satisfactory pressures, temperatures, valve positions, propellant, and pressurant quantities, etc.).

- Primary or Backup Assembly Status - Provides an indication of whether the redundant or primary subsystem assemblies are in use.

- Tank Pressures and Temperatures - Verifies that normal operating conditions exist and whether pressure and temperature variation trends are normal.

The more detailed periodic checkout is scheduled over three-month intervals and prior to initiation of a critical operation such as an artificial experiment.

In cases where a fault is detected, the applicable portions of the periodic checkout procedure will be needed to determine the maintenance required. The periodic checkout includes:

- Leak and Functional Tests - These verify the basic subsystem integrity. Leak tests are performed both manually and automatically. The manual checks are required to detect low-rate leak conditions which may be detrimental over a long period of time if uncorrected. The functional tests check both the electrical circuits and component (valves, etc.) operations.

- Pressure Regulation and Thruster Performance Checks - The thruster performance checks require monitoring and recording of chamber pressure and temperature versus time during the firing interval. Automatic/programmed test-sequencing and high-speed data sampling at a rate of 250 samples/second are necessary.

- Instrumentation Calibration - One or two-point calibration is required for both temperature and pressure transducers. Use of standard gages or known pressure and temperature references is required.

- GN&C/Propulsion Subsystem Interface Checks - Simulated programmed control commands are needed to verify the GN&C propulsion interfaces. Other subsystem (DMS and Electrical Power) interface integrity checks are also performed as part of the periodic functional tests.

- Propellant Sampling - The quality of the propellant must be determined through taking a sample and returning it on the ALS for analysis on the ground.

- Subsystem Hardware Life History Log - Automatic storage and display of data is desirable.

In general, the test sequence for the detailed periodic checkout should first include an evaluation of general subsystem status and safety critical parameters followed by LRU-level checkout. The general test sequence should be to test the high pressure storage assemblies first and then the subsequent downstream assemblies. A total candidate sequence follows:

(a) Subsystem Status Check

- Pressure
- Temperature
- Valve Position
- Propellant Quantity
- Identification of On-Line Equipment

(b) Pressure Transducer Calibration Check

(c) Verify Purge (Checkout) Assembly Operational Status

- Functional
- Pressure (Regulation)

(d) Subsystem Gross Leakage Test

- Pressure Trend/Analysis

(e) Verify Safety Critical Caution and Warning Circuits (over pressure, relief actuation, regulator switchover, etc.)

- Electrical Continuity/Response

(f) Bellows Leak Test

- Gas Analysis of Pressurant

(g) Pressure Control Assembly Check

- Backup Regulator Switchover Circuit
- Regulation
- Pressure Switch Setting

(h) High Pressure Isolation Valve Check

- Leakage - Pressure Trend Analysis
- Functional

(i) Test Low Pressure Manifold and Propellant Tank (Gas Side) Isolation Valves

- Leakage - Pressure Trend Analysis
- Functional

(j) Test Propellant Isolation Valves (Tanks and Manifolds)

- Leakage - Pressure Trend Analysis
- Functional

(k) Check Tank Switching Circuit

- Functional

(l) Thruster Modules

- Isolation Valves - Leaks and Functional
- Isolation Circuits
- Thruster Valves - Leakage
- Thruster - Functional and Performance Firing

(m) Miscellaneous

- Vent Valves - Leak and Functional
- Catalytic Nonpropulsive (propellant) Vent Device - Functional
- Temperature Sensors - Calibration
- Resupply Subassembly

(n) GN&C - Propulsion Integrated Subsystem Test

- Functional - Firing Commands
- Performance - Chamber Pressure and Temperature versus Time Verification

6.1.2.1.3 Fault Isolation

Fault isolation checks within the High-Thrust Propulsion System consist essentially of portions of the detailed periodic checkout sequence previously described. An example of isolating a fault following the detection of a change in the regulator isolation valve is depicted in Figure 6-2. The following steps are required to isolate a fault in the pressure control assembly. The example is considered to be one of the more complex fault isolation tests for the high thrust system.

1. Verify subsystem operational status.

2. Calibrate hi pressure and pressurant manifold pressure transducers.

3. Verify purge (checkout) assembly is operational.

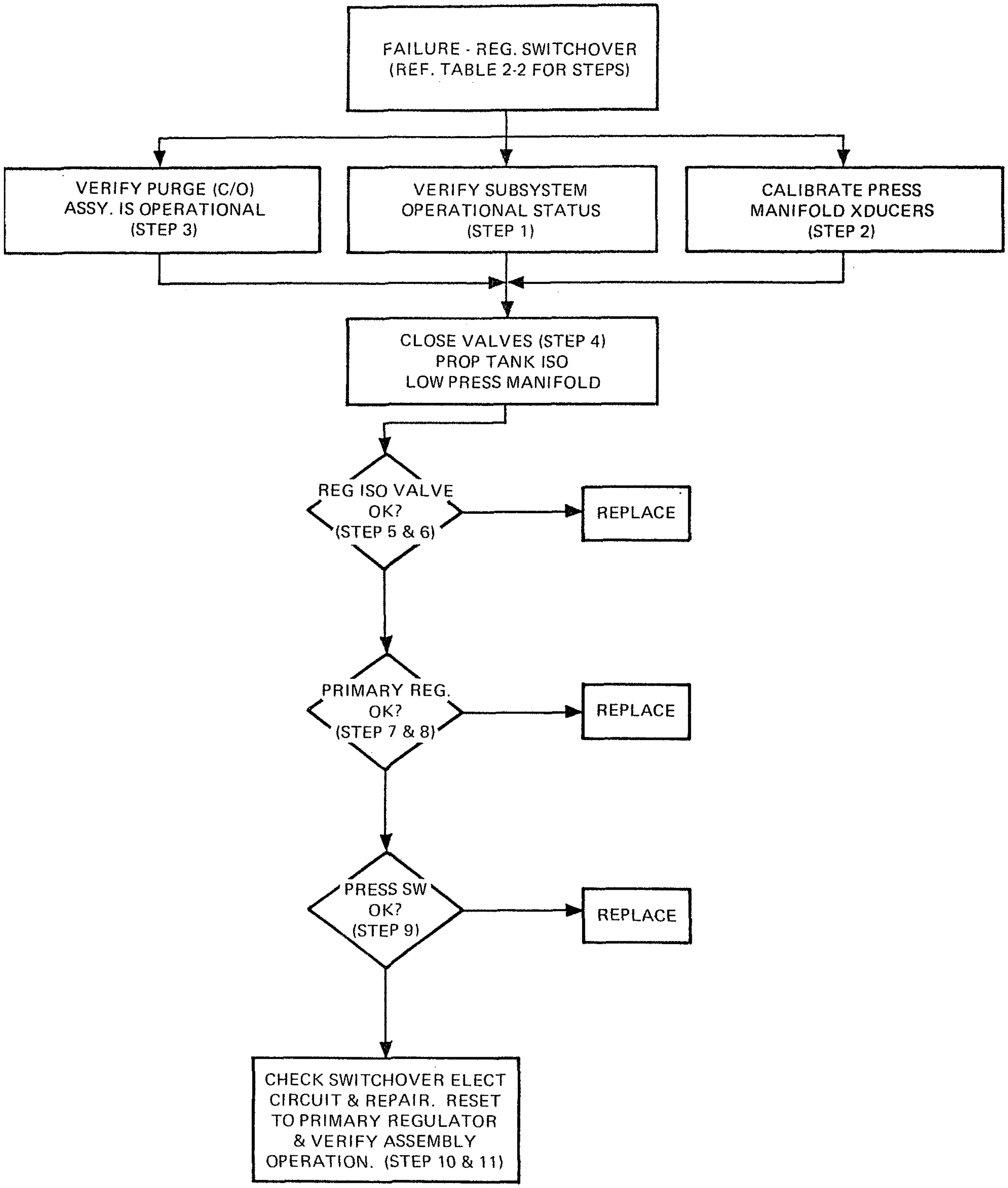

Figure 6-2. Fault Isolation Check Pressure Control Assembly

4. Close propellant tank pressurant isolation valves, low pressure manifold isolation valves, and regulator isolation valves.

5. Verify regulation isolation valves are functional.

6. Vent low pressure manifold.

7. Open primary regulator isolation valves.

8. Monitor downstream regulation pressure - either a high or low regulation pressure failure indication should occur. If the regulator proves to be satisfactory, the pressure switches or switchover circuits are malfunctioning.

9. Close regulator isolation valve and provide pressure switch test pressures from the purge (checkout) assembly. Verify pressure-switch actuation pressure valves. If the pressure switch performance is satisfactory, the control logic circuits must be malfunctioning.

10. Conduct electrical switchout circuit repair and checks as required. (Note: The Electrical LRUs have not been identified for the Propulsion Subsystem.).

11. Reset regulator switchover circuit and assure the pressure control assembly is in an operational state.

6.1.2.2 Low-Thrust System

The Low-Thrust Propulsion System uses EC/LS-produced biowaste gases (CO_2, H_2O, CH_4) and stored water as propellant for resistojet thrusters. These thrusters have a thrust level of 25 millipounds, and are used in a high duty cycle mode (25-80 percent) to provide station orbit maintenance and, if desired, CMG desaturation. The system consists of compression pumps, heat exchangers, accumulators, supplementary propellant tankage, thrusters, and the necessary valves, switches, etc., for system control, checkout, etc.

Normal system operation is in the orbit-keeping and attitude control mode and is fully automatic. Thruster selection and control is derived by the DMS computational equipment on the basis of inputs from the GN&C Subsystem. The DMS also controls the subsystem configuration parameters such as propellant and pressurant selection. These parameters are primarily a function of impulse requirements and available stores. Manual control capability is provided to allow crew override if required due to a malfunction or other reasons. On-orbit checkout of the low-thrust system includes a combination of continuous monitoring, daily operational status checks and trend analysis, a detailed periodic checkout every three months, and fault isolation activities. Appendix I-3 contains the measurements and stimuli required to check out the Low-Thrust Propulsion System.

6.1.2.2.1 Status Monitoring

Continuous monitoring of low thrust system parameters is conducted to detect faults and to initiate switching to redundant LRUs when necessary. This is accomplished by a combination of integral sensing/switching provisions and DMS action. The integral implementation is utilized primarily in the case of failures which demand immediate and direct action to relieve a potentially hazardous condition. An example is excessive pressure on the outlet side of a pressure regulator. The condition would be detected by a pressure sensitive switch which, when activated, would automatically operate solenoid valves to isolate the regulator and switch to a parallel redundant unit. Notification of the occurrence would be given the DMS which would then proceed to notify the crew and accomplish other required reactions, such as fault verification, repair direction, or modification of Space Station operations. Faults which are less critical in nature and those for which diagnosis and corrective action require the computational and analytical capability of the DMS are processed by automated DMS routines. Table 6-2 lists a number of representative failure modes and the associated subsystem or DMS action.

6.1.2.2.2 Periodic Checkout

As for the High-Thrust System, daily operational status checks are required for the Low-Thrust System. These daily checks are basically the same as those described in Subsection 6.1.2.1.2.

A more detailed checkout of the Low-Thrust System is conducted every three months. All redundant elements within the system are checked, including a verification of the proper operation of all valves. The daily checks only verify valve positions, not valve actuation. A possible test sequence to be used in the periodic checkout is:

- Subsystem Status Check
  - Pressure
  - Temperature
  - Valve Position

Table 6-2. Representative Failure Modes and Associated Subsystem or DMS Action

COMPONENT	FAULT	ACTION
Pump	Excessively high or low pump speed	DMS turn off pump and isolate by closing appropriate valves.
Pump	Out-of-limit inter-stage temperature	Same as above, initiated by measurement in EC/LS Subsystem.
Storage bottle and/or High Pressure Manifold	Excessive pressure	Relief assembly vents gas(es). Integral control.
Regulator	Out-of-tolerance regulation	Switch to alternate regulator and isolate by closing appropriate valves. Integral control.
Flow Control Valve	Fail close or open	DMS switch to alternate feed system and isloate by closing crossfeed valves.
Thruster	Heating element over temperature	Integral thruster cutoff.
Thruster	Out-of-tolerance power consumption	DMS switch to alternate thrusters.
Thruster	Inlet valve will not close	DMS switch to alternate thruster and isolate module.
Fittings	Leakage	DMS or crew inspection determine source and isolate. Switch to alternate assembly.
H_2O Vaporizer	Out-of-tolerance heat input	DMS switch to alternate vaporizer. Turn off heaters and close isolation valves.
H_2O Storage	Out-of-tolerance pressure	DMS-switch to alternate tank and isolate.

- Propellant Quantity
- Identification of On-Line Equipment
- Pump Speed
- Vaporizer

- Pressure Transducer Calibration Check (only every 6 months)
- Subsystem Gross Leakage Test
  - Pressure Trend Analysis
- Verify Safety Critical Caution Circuits (over pressure, relief actuation, regulator switch-over, etc.)
  - Electrical Continuity/Response
- Flow Control Check
  - Backup Regulator Switchover Circuit
  - Regulation
  - Pressure Switch Setting
  - Valves
- Thruster Modules
  - Isolation Valves - leaks and functional
  - Isolation Circuits
  - Thruster Valves - leakage
  - Thruster Heaters
- Interface Checks
  - GN&C
  - EC/LS

6.1.2.2.3 Fault Isolation

Fault isolation within the Low-Thrust System typically involves an input/output relationship such as regulator inlet versus outlet pressure, valve command versus position, etc. A typical fault isolation flow is depicted in Figure 6-3 for a CO_2 tank isolation valve failure. The failure is detected as a result of monitoring valve position, and the crew is notified of switchover to the redundant valve. For this case, the failure is either the valve or in the DMS control logic or data acquisition elements.

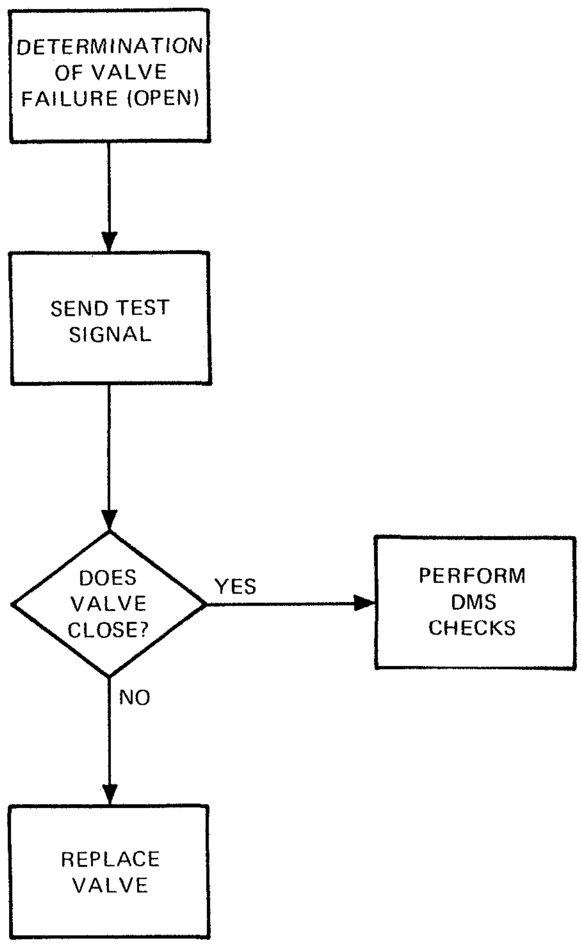

Figure 6-3. Low Thrust System CO_2 Tank Isolation Valve Failure (Open)

The capability to substitute redundant elements provides a very useful fault isolation tool for the Low-Thrust System. This may be used in the case of the pressure regulator assemblies, compression pumps, and water vaporizers for example, where solenoid-controlled isolation and cross feed valves allow rapid switchover to the redundant elements.

Another valuable fault isolation tool is the onboard crew member. His powers of observation and reasoning in some cases enable him to detect and isolate faults which may elude the efforts of an automated system or which are difficult to detect by instrumentation, as in the case of fluid leakage. Planned utilization of the crew for routine fault isolation will be minimized, however, due to the limitations on available manpower resources.

6.1.3 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SUBSYSTEM

The Environmental Control and Life Support (EC/LS) Subsystem provides the atmosphere supply and control, atmosphere reconditioning water management, waste management, and thermal control functions for the Space Station, including the IVA/EVA Systems. Proper operation of the subsystem is essential to the habitability of the Space Station and to the lives of the crew. The subsystem therefore features a high degree of reliability which is achieved through provision of redundancy and backup operating modes.

The EC/LS Subsystem normally operates in an automatic closed-loop mode under overall supervision of the Data Management System (DMS). An important function of the DMS will be to maintain a vehicle mass balance to project expendables use rates and to identify equipment which is not reclaiming oxygen and water at the required efficiency. The measurement/stimulus list for the EC/LS is given in Appendix I-4.

6.1.3.1 Status Monitoring

Status monitoring instrumentation is provided for major parameters which reflect performance and operational status of the subsystem. Any appreciable degradation of subsystem performance is detected by limit checking. Depending upon the nature of the fault the crew receives a normal malfunction notification or a caution or warning alarm. Caution pertains to a condition of station degradation where some station activities may be curtailed. A warning is given when life critical systems are involved and the crew is in immediate danger.

Fault detection acceptance or rejection criteria are based on historically or analytically derived definitions of normal operation. Each individual fault detection parameter must be considered separately and acceptance or rejection criteria selected which accurately reflect performance. Limits on acceptance criteria are made sufficiently broad to avoid premature or erroneous fault warnings, yet with adequate margin to avoid the development of hazardous conditions.

Normally, not all the EC/LS equipment is operating at a given time and an inventory of on-line assemblies must be kept by the DMS. This inventory is required to condition limit checking and other fault detection procedures so as to prevent false malfunction warnings for shutdown equipment. Also, EC/LS assemblies which operate in a cyclic mode possess parameters which vary greatly over the cycle. Provisions must therefore be made for conditioning the tests of these parameters with the normal for that point in the cycle.

6.1.3.2 Trend Analysis

Trend analysis is utilized for functions which are subject to performance degradation of known and measurable characteristics. These include electrolysis cells, reverse osmosis membranes, adsorption beds, and evaporator wicks. By observing the change in the major performance parameters, component replacement can be scheduled at a convenient time for the crew. Hazardous conditions can be avoided by trend analysis prediction of out-of-tolerance conditions. Trend analysis is also used to monitor expendable use rates. This pinpoints locations of excessive expendables use rates indicative of possible leakage or other failures, and also provides a basis for resources management and resupply planning activities. An example of this application is the use of nitrogen repressurization history to detect abnormal cabin repressurization rates which may be indicative of a leak in the vehicle pressure shell.

6.1.3.3 Periodic Checkout

The EC/LS is periodically checked out to determine its status at specific periods in the mission. Checkout just prior to resupply is advantageous so that any deficiencies can be identified and replacements can be included in the resupply provisions.

The general checkout sequence addresses the least dependent functional group first. As an example, the thermal control equipment is checked out first because its operation does not depend on other functional groups. However, many other assemblies depend upon proper operations of the thermal control equipment. By verifying thermal control, deficiencies due to inadequate heating and cooling are eliminated as possible causes of deficiencies in EC/LS equipment. The sequence for checkout of functional groups follows the sequence below.

1. Thermal Control

2. Atmosphere Supply

3. Atmosphere Reconditioning

4. Water Management

5. Waste Management

6. IVA/EVA

Sequencing within an assembly group follows the same general procedure; the assemblies and LRUs which are least dependent are checked first. Where applicable, test sequencing is established by combinational analysis requirements.

Only a portion of the LRUs will be operating at a given time during the mission. Therefore, in order to accomplish checkout, stimuli will be provided by the DMS to exercise the EC/LS.

Units on standby redundancy are checked out by switching operation from the normally operating unit.

Acceptance or rejection criteria will consist of detecting on-off type components which fail to operate or detecting equipment which falls short of qualitative performance requirements. In some cases, on-off equipment is tested for performance as well as actuation. An example is a shut-off valve which is tested for actuation and for leakage. Leakage beyond allowable tolerance results in degraded subsystem performance and is considered a fault. Tolerance bands are chosen sufficiently broad to avoid premature fault identification and high utilization of spares. In many cases, some performance degradation can be tolerated in order to extract more life from components.

6.1.3.4 FAULT ISOLATION

Once the fault detection function has identified an abnormality in the EC/LS, tests are performed to identify the failure down to the LRU level. This entire procedure can be performed by the DMS in nearly all cases. A major exception is fluid and gas lines, where the exact location of a failure such as a blockage or leak cannot in some cases be performed by inplace instrumentation. Portable instrumentation and visual inspection procedures adapt readily to this application.

Fault isolation functions utilize much of the procedure software which is used for the periodic checkout function. The major difference is that the fault detection process has generally narrowed the failure location down to a small portion of the EC/LS. The point of entry into the functional test procedure is therefore determined by the malfunction indicated, and only that portion of the test necessary to identify the failed LRU is executed. Following repair or replacement, proper operation is verified by retesting.

A typical fault isolation flow is illustrated in Figure 6-4. This flow is initiated upon detection of excessive CO_2 in the cabin atmosphere and proceeds to isolate the fault to the appropriate LRU or to determine the required corrective action.

6.1.4 RF COMMUNICATIONS SUBSYSTEM

The RF Communications Subsystem contains the receiver, transmitters, power amplifiers, transponders, modems, and antenna systems to provide radio frequency communications between the Space Station and the ground, DRSS, Shuttle, free-flying experiment modules, and EVA crewmen. The subsystem operates in the S, K_u, and VHF bands.

On-orbit checkout activities required to insure the availability of the subsystem include monitoring of its normal operational outputs, performing periodic checks, and selecting fault isolation routines associated with the loss of a communications function. In addition, some trending and calibration are required.

The measurements and stimuli associated with these checkout activities are identified in Appendix I-5. All analog and RF stimuli are generated by the subsystem but controlled by the DMS. Conditioning of sensor outputs is also integral to subsystem LRUs and results in all measurements being compatible with DMS data acquisition elements.

Go/No-Go decision outputs are provided where possible for checkout of the RF communications subsystem. The acceptance/rejection criteria associated with the occurrence of an event such as primary power ON/OFF, modulation output present, switch position selected, and channel or mode selected are straightforward. A bilevel output is either present or absent and would be indicated by two distinct voltage levels. An absolute acceptance/rejection criterion associated with analog responses such as RF power output level, VSWR level, and AGC output level, on the other hand, is more difficult to establish. This is due to design variances between equipment and the accuracy of the individual measurement. For instance, the K_u-band PA may be specified to deliver not less than 10 watts of RF power, and this would be indicated by a 4.0-volt analog output. A tolerance of $\pm$ 10 percent due to design and measurement variances results in a range of outputs from 3.6 to 4.4 volts. Reliance on an absolute level could result in the rejection of a unit that is operating normally. Therefore, the analog outputs should be utilized primarily for trend analysis purposes.

The checkout of the RF Communications Subsystem can be automatically controlled by the DMS and should require minimal crew participation. The crew participation would be limited to calling up preprogrammed fault isolation and periodic checkout routines and interpretation of anomalies.

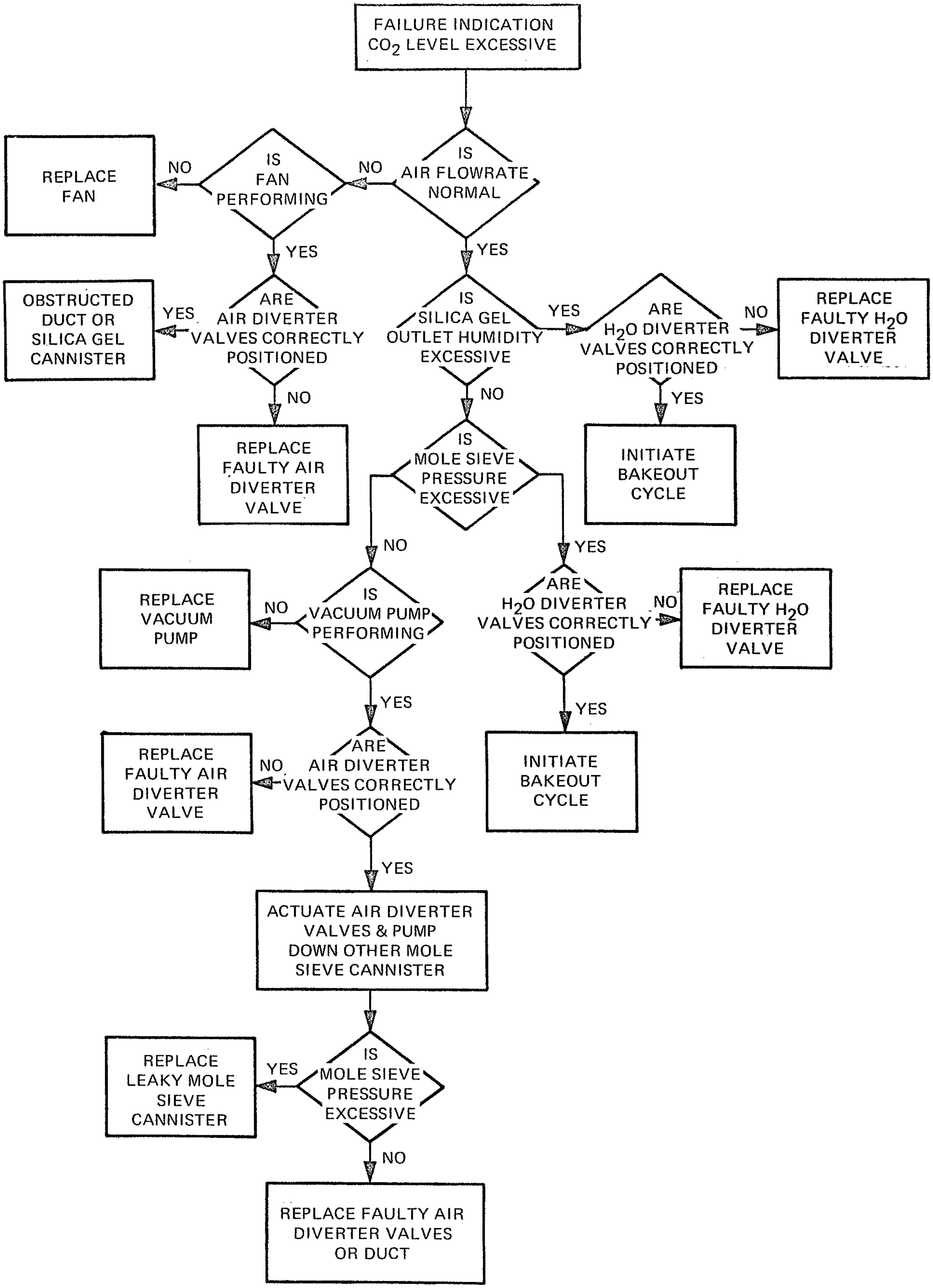

Figure 6-4. Logic Diagram for CO_2 Concentration Fault Isolation

6.1.4.1 Status Monitoring

During normal operation of the subsystem, only two different types of parameters are monitored on a nearly continuous basis. These are the transmitter or exciter and power amplifier RF power output levels, and the receiver AGC output levels. These noncritical parameters are sampled once per minute. This sampling can be performed during normal operation of the subsystem without the need for stimuli. In the case of AGC output level, for example, the signal stimulus is the modulated RF signal transmitted by the Shuttle, free-flying experiment module, etc. Since the AGC level varies as a function of received signal strength, this parameter should be compared on a sample-to-sample basis to detect large changes in output level. Unless a failure occurs, the RF power output should stay fairly constant during a normal operating period. For power output levels, the RF output of the exciter associated with the power amplifier provides the required input stimulus. Measurement of power output during normal operation actually provides a better indication of overall performance than would a check of the power amplifier by itself.

Although several parameters are monitored continuously during subsystem operation, none of these can be classified in a caution or warning category.

6.1.4.2 Trend Analysis

To detect graceful degradation in Communication Subsystem receivers, exciters, power amplifiers, and transmitters, internally generated AGC, RF stimuli, AGC outputs, and power outputs are periodically sampled. The internally generaged RF stimuli are necessary to obtain an accurate indication of the AGC output levels. Sampling should occur approximately once per day for equipment utilized to support the Shuttle, free-flying experiment modules, and direct-to-ground links. Equipment that supports the primary link between the Space Station and the relay satellite, on the other hand, should be sampled about once per hour.

6.1.4.3 Calibration

The only calibration functions that have been identified are the RF power levels at the high-gain antenna feeds and low-gain antenna elements. The measurement of RF System insertion loss is required after the replacement of an LRU in the RF Transmission System to verify that the unit has been properly replaced.

6.1.4.4 Periodic Checkout

Periodic checks of subsystem status and availability are performed at once-per-month and one-per-week intervals. The monthly checks should be performed several days ahead of anticipated operational usage. This primarily pertains to that equipment utilized to support the Shuttle and experiment modules. During the artificial-gravity portion of the mission, the S-band equipment utilized for the direct-to-ground link should be checked once per week. After completion of artificial gravity, these checks can be performed at monthly intervals. Week-by-week checks should also be performed on the transmitters (exciters and power amplifiers), receivers, signal interface modems, and High Gain Antenna System utilized for the Space Station relay satellite K_u-band link.

The procedure for periodic checkout requires systematic checks performed on a group of LRUs associated with a particular mission support function. Except for the High Gain Antenna System, the following represents a periodic checkout procedure for a typical set of RF link equipment.

1. Apply primary power to all units.

2. Monitor primary power indication.

3. Check for completion of power amplifier warm-up cycle.

4. Monitor exciter, power amplifier, and antenna feed RF power output levels.

5. Monitor VSWR levels at power amplifier output and antenna feed.

6. Apply modulation input stimulus.

7. Monitor modem and exciter outputs for presence of modulation.

8. Apply modulated RF signal at input to low noise preamplifier.

9. Monitor preamplifier output level and receive AGC output level.

10. Monitor modem and receiver outputs for presence of modulation.

11. Switch to redundant preamplifier and repeat steps 8, 9, and 10.

12. Apply known antenna position control input.

13. Monitor antenna position output indication and compare with input.

6.1.4.5 Fault Isolation

Fault isolation of the RF Communications Subsystem is performed on a systematic basis on a group of LRUs that are associated with the loss of a particular function. A typical fault isolation flow diagram is depicted in Figure 6-5 for the case where no video signal is received from the ground. This particular routine culminates in the identification of an LRU to be replaced or calls for further testing of the High Gain Antenna System or interfacing portions of the Data Management Subsystem.

6.1.5 STRUCTURAL SUBSYSTEM

The Structural Subsystem forms and maintains the compartment divisions of the Space Station. It provides a pressure shell/structural shield designed for high damage resistance from external projectiles (meteorites), and eliminates stresses due to orbital thermal cycling.

Ports are provided on the exterior structure shell to accommodate docking of resupply/logistic and experiment modules which enhance orbital life and versatility of the basic station design.

The Structures Subsystem also includes provisions needed for deployment of the spent S-II stage as a counterweight for the artificial gravity mode of operation.

Operational assessment of the Structures Subsystem elements is generally accomplished by monitoring of measured system parameters, and to a significant extent, by visual inspection. Operational measurements for the subsystem are predominantly of the event monitoring type intended to inform the crew of the immediate configuration/status of the subsystem. Functions to be monitored and displayed included position/event data on docking rings, hatches and airlock doors, and antenna booms. Analog measurements/display include counterweight position and pressures, temperatures, and power monitoring of compartment divisions and functional units which provide pre and post event data to the crew for condition assessment. It should be noted that the operational data requirements for this subsystem are extremely event-oriented and that the frequency of use is low (ave 1/mo). Hence, the impact upon the Data Management Subsystem for real-time continuous data display and computation is also minimal (e.g. data callup in lieu of full-time dedication is acceptable). Measurement and stimuli requirements for the Structures Subsystem are contained in Appendix I-6.

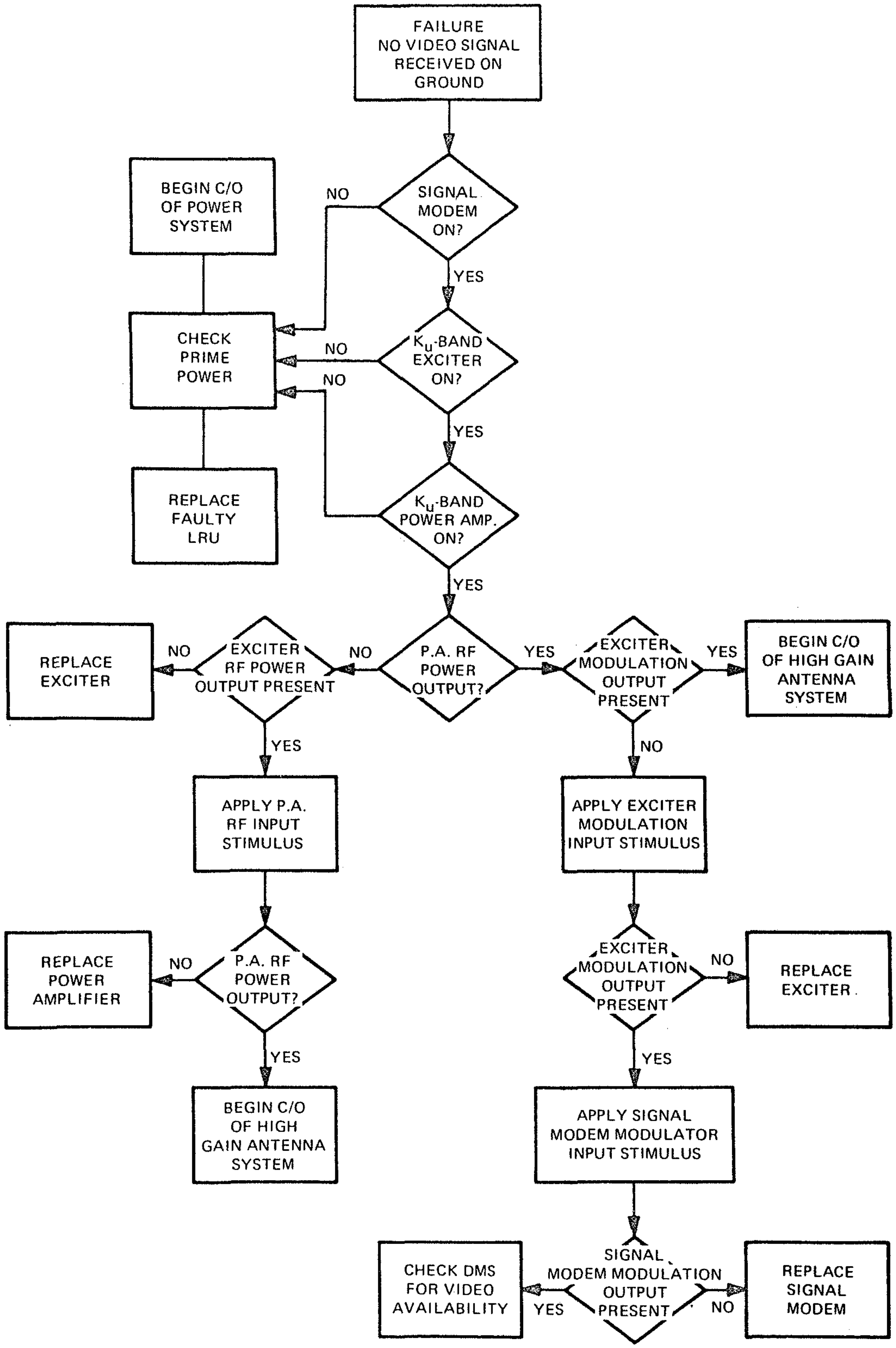

Figure 6-5. Typical Fault Isolation Routine Flow Diagram

6.1.5.1 Status Monitoring

Due to the nature of the Structures Subsystem the requirements for continuous status monitoring for purposes of fault detection are quite limited. Such monitoring requirements that do exist utilize selected operational status parameters such as temperature and pressures. Required sampling rates are relatively low and are not critical. Acceptance rejection criteria are based upon comparison of measured values with predetermined limits. Support from the EC/LS Subsystem monitor of atmosphere consumption is utilized for detection of abnormal compartment leakage. Detection of out-of-limit conditions results in notification of the crew. Since no safety critical functions are involved, no automatic corrective action is required. Fault isolation is accomplished by combined crew/automatic procedures. Automatic fault detection is heavily supplemented by crew observation of normal subsystem status displays and of the actual equipment during operation.

No caution/warning functions have been identified in association with the Structures Subsystem. Certain related functions such as hull leaks are covered by EC/LS caution/warning functions.

6.1.5.2 Trend Analysis

No trend analysis requirements have been identified for this subsystem.

6.1.5.3 Periodic Checkout

Periodic checkout of the Structures Subsystem elements is planned to occur either prior to a scheduled event such as module docking and artifical-g deployment/termination or during specific operational times such as shift changes where status information pertaining to compartment configuration (hatch positions) and antenna positions is of interest to the oncoming crew.

Functional checkout of the docking mechanism, which includes visual inspection and extension/retraction of the docking ring is conducted prior to a scheduled docking event to verify operation of the mechanism before committing the arriving module to that port location. This checkout is scheduled sufficiently in advance to permit reassignment of the module in the event of malfunction. Likewise, periodic start-of-shift checks of the station configuration are planned to alert the oncoming crew as to overall subsystem status.

Periodic review of EC/LS atmosphere consumption trend analysis is also planned to assess leakage of the pressurized compartment(s) to establish "as is" acceptance or need for corrective action.

6.1.5.4 Fault Isloation

The fault isolation process to the LRU level for the Structures Subsystem lacks the complexity generally associated with electronic subsystems due to the nature of the hardware elements involved. In most instances malfunctions are obvious from the operational data being displayed or by visual inspection, and therefore require a minimum of DMS support. Isolation of leaks in the pressure shell of the station will utilize a combination of pressure decay, visual inspection, and sonic detector techniques. Pressure decay tests, accompanied by acoustical leak sensors on the shell surface, will permit isolation to a specific compartment/location. If the leakage occurs in association with an event such as EVA or docking visual inspection for seal/structural damage of the hatch/door involved will be utilized. Scuffing, wear, or puncture of a seal will be suspect. Isolation of leaks in the basic structure shell will utilize the ultrasonic detection technique which employs the use of portable detectors capable of sensing ultrasonic energy in the frequency range of 35-50 KHz produced by gas flow through an orifice.

6.1.6 ELECTRICAL POWER

The Electrical Power Subsystem (EPS) consists of dual Isotope/Brayton power conversion systems and a transmission, conditioning, and distribution system.

6.1.6.1 Power Conversion System

The Isotope/Brayton System (IBS) produces the electrical power for the Space Station by converting thermal energy from plutonium isotope heat sources to electrical energy through Brayton cycle turbine-driven alternators.

The IBS consists of the heat source assemblies, heat exchangers, rotating power conversion units, Gas Management System, and voltage-regulator/speed control assemblies. The system also includes an atmosphere reentry and recovery system (IRV) for emergency jettison and return of the heat sources.

Appendix I-7 contains a listing of the measurements and stimuli associated with the IBS.

Operation of the IBS is in a closed-loop automatic mode and is controlled by the Data Management System (DMS).

To provide heat source control, the compressor inlet temperature, turbine inlet temperature, heat source capsule hot spot temperature, and BeO hot spot temperature are processed by the heat source control logic. Position indicators tell when the heat source is in the "operating" mode and when it is extended and radiating into space in the "emergency cooling" mode.

The power conversion Brayton gas loop is controlled by the turbine inlet temperature, the compressor inlet temperature, the bearing cavity pressure, and the compressor outlet pressure.

In addition to the gas loop instrumentation, there are several electrical parameters included with the Power Conversion System to provide fault detection and control for the alternator. These are alternator output, load bus, series and shunt field currents, alternator output voltage, and frequencies. The voltages, currents, and frequencies together with voltage regulators/exciter and speed control circuitry provide the signals necessary to maintain specified speed and voltage regulation. They also provide the signals vital to normal startup and shutdown as well as emergency control in case of critical level out-of-tolerance voltages, currents, and speeds.

The Gas Management System contains pressure and temperature transducers for monitoring the status of the reserve supply of the Xe-He gas for the power conversion loop. It also includes several valves to provide a controlled gas supply to the thrust bearings, journal bearings, and for maintenance of the loop gas inventory. Auxiliary contacts on each valve act as positive position indicators to show the status of the valves.

The IRV is utilized only for emergency disposal of the heat source. It consists of an ejection mechanism, passive stabilization and control system, ballute type descent system, and recovery aids such as radio beacon and flashing light.

6.1.6.1.1 Status Monitoring

Status monitoring is utilized on selected performance parameters to detect system faults. Acceptance or rejection of status measurements is based upon comparison of the measured values against predetermined limits and/or against parallel redundant parameters.

The majority of the status monitoring parameters are safety critical and are treated as caution and/or warning parameters. Detection of an out-of-limit condition in one of these measurements results in activation of the crew alarm and also in the initiation of automatic fault isolation and safing procedures. Certain parameters are identified in both the caution and the warning category. These involve two-level limit checking.

6.1.6.1.2 Trend Analysis

Trend analyses are applicable to several of the IBS functions. In particular, analysis of temperatures and pressures in the Brayton loop and heat rejection loops is useful in ascertaining the efficiency of the system and spotting degradation in performance. The trends of critical heat source temperatures are of interest from a safety standpoint.

6.1.6.1.3 Periodic Checkout

Periodic tests are required to supplement the continuous status monitoring in order to make a quantitative evaluation of system operating characteristics and to verify the operation of standby or inactive systems. Items in the latter category include the drive mechanisms for extending the heat sources to their emergency cooling positions and the IRV Systems. The test sequence is not critical but normally begins with verification of the DMS control interfaces, followed by checking of the IRV Systems and heat source extension mechanisms. It should be noted that functional testing of the extension systems requires short-term interruption of power generation in the unit being tested. Power distribution and consumption during this period must be managed accordingly, and proper operation must be reverified upon completion of the test.

6.1.6.1.4 Fault Isolation

The IRV heat source and Brayton power conversion loop are major subsystems that are line replaceable units. The Gas Management and Heat Rejection Systems are line replaceable at the component level. Electrical control components such as the voltage regulator exciter and speed control are line replaceable as individual units. Integration of the radiator cooling flow tubes into the vehicle structure precludes inclusion of the Heat Rejection System as a line replaceable unit. Instead, the components are either line replaceable or have built-in redundancy. The Heat Rejection System itself is a redundant element of the Power System so that the Power System electrical production does not have to be disturbed during the replacement of components. The pump motor has instrumentation to isolate pump failures (pump pressure out and flow rates) from power failure (pump current and voltage). Deterioration of the pump motor can be detected from trend analysis of the power drawn by the unit and the deterioration can be segregated from deterioration of the fluid cooling loop or coolant by comparing the change in power drawn (motor current) with the pump head (pump outlet pressure). Changes in individual flow rates, temperature rise across cold plates, and hot spot temperatures can be used to isolate cooling (cold plate) failures from failures in the components they are designed to cool. Radiator outlet temperature is an important parameter for judging the condition of the fin surface coating of the radiator. At any instance, only one heat rejection loop for each Power Conversion System is operating and only one of the two pumps is in operation so that only one set of transducer signals are needed to provide data. The hot spot temperatures are critical parameters, however, and the triple redundancy is required to isolate instrumentation faults from operating system faults to prevent false caution signals.

A typical fault isolation flow is illustrated in Figure 6-6. Here a fault in the heat rejection pump gives the first indication of a fault by setting off the caution alarm for the isotope heat source capsule temperature. The chart demonstrates that even though the fault occurred in a component far removed from the parameter that gave the indication, adequate instrumentation is available to isolate the fault at the faulted component. In actual practice, more than one fault alarm may occur (such as capsule temperature and pump hot spot temperature, or capsule temperature and compressor outlet temperature) which would lead directly to isolating the fault.

6.1.6.2 Transmission, Conditioning, and Distribution

This section discusses the monitoring and control requirements for the Transmission, Conditioning and Distribution (TCD) portion of the EPS. Appendix I-8 provides a TCD measurement/stimulus list which identifies the specific parameters, stimuli, and response functions required to check the system and to determine its operational status.

The TCS System requires a minimum of crew supervision. Operational parameters consist of alternator feeder current readouts, battery status, and principal primary and secondary bus voltages. The feeder current readouts, together with alternator output power displays establish the degree of load balance between the two Brayton PCS units. A small amount of unbalance is inherent in the system. Crew action is required only if the normal range is exceeded (as detected by the Power Management Assembly), or if high experiment activity requiring maximum possible power from the Brayton machines is imminent. Crew response under these conditions is to shift load from one machine to the other by selective switching of loads.

Battery status displays and readouts of selected bus voltages provide additional information for evaluating system performance and capability for accepting additional load. The ability to call up the status of any other system element, as may be deemed necessary for evaluation of a particular operational condition, provides the flexibility required to ensure adequate status assessments at any given time.

All circuit breakers and contactors for power transmission lines, source and distributor buses, and power conditioning equipment can be remotely controlled. Many are controlled by signals from automatic protection equipment such as differential or reverse current relays. Remote control is also required to provide for either manual or programmed reconfiguration of the TCD System following automatic fault-clearing operations, as well as for facilitating reconfiguration to match changing load or other operational conditions. Additional controls are provided to support checkout functions.

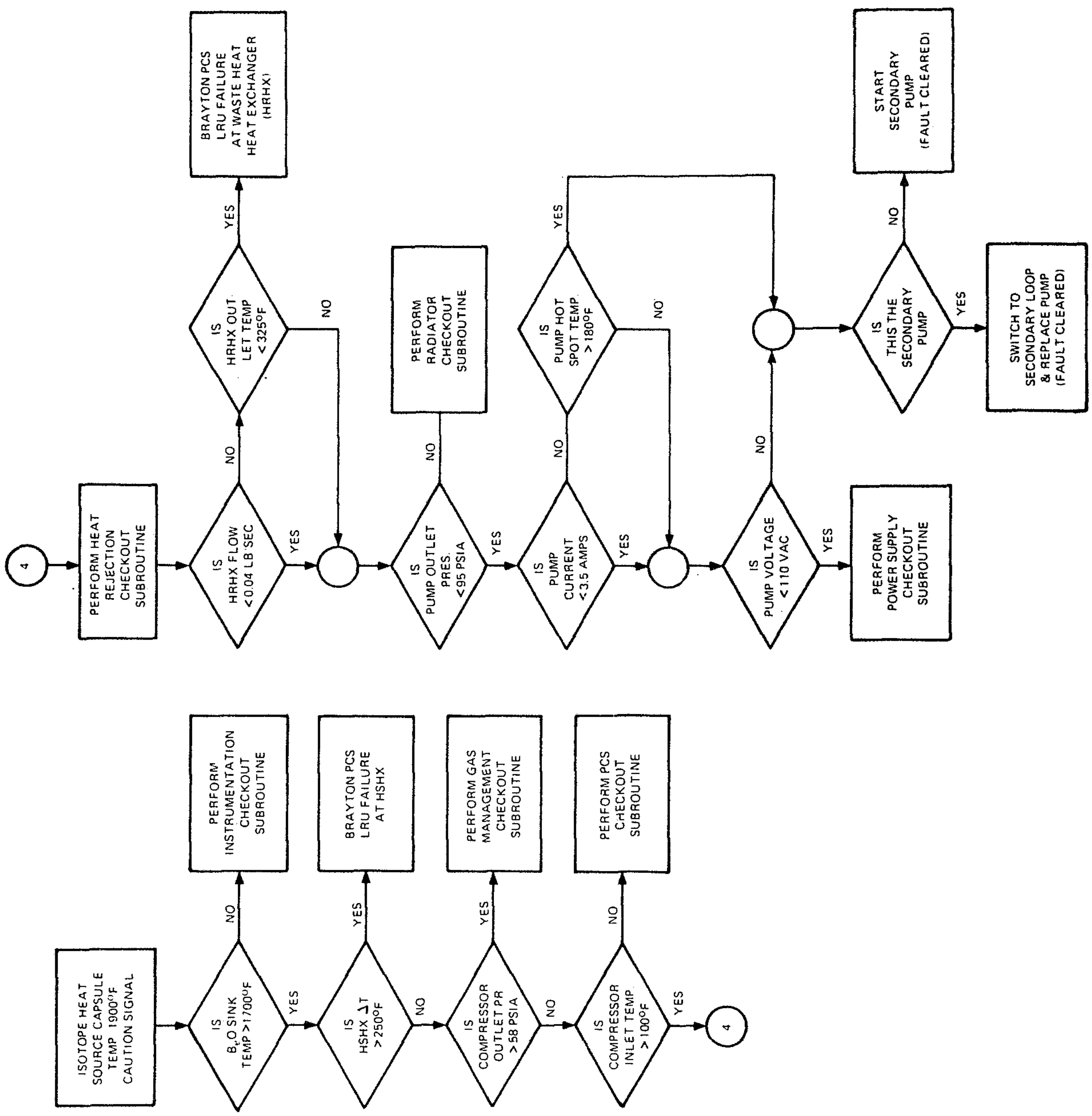

Figure 6-6. Typical LRU Malfunction Isolation Flow Chart

It is important to note at this point that no capability is shown for remote control of individual circuit breakers in the distribution circuits to the loads. It is assumed for the purpose of this study that all switching of loads is accomplished in the load systems themselves rather than by opening and closing circuit breakers in the power lines to individual loads. Final definition of load switching control design is yet to be developed.

6.1.6.2.1 Status Monitoring

Continuous monitoring is required to detect out-of-tolerance conditions for parameters such as alternator load-sharing, principal bus voltages, and equipment temperatures. Continuous monitoring is also required to detect abnormal events. These include relay trips, circuit breaker and contactor trips, and power conditioner overload (current limiting signal).

Alternator feeder currents and most bus voltages are sampled at the rate of six per minute. Feeder current values should stay fairly constant during normal operation, but as previously mentioned, some unbalance is inherent. A sampling rate of six per minute for bus voltages should eliminate the effects of voltage transients (assuming a fault signal is generated only if an out-of-tolerance condition is sensed in two consecutive samples), while still providing a reasonable response time for follow-on corrective action. The higher sampling rate of once per second for 28 Vdc and 400 Hz load bus voltages assures minimum delay in detecting out-of-tolerance voltages at the principal load interfaces. For this higher rate, abnormal voltage should be sensed in a minimum of five consecutive samples before a fault signal is generated.

Equipment temperatures are sampled at a rate of four per hour. Considering thermal lags inherent in the equipment being monitored, this rate should be adequate for all but catastrophic failures.

Relay trips are nominally monitored at a one-sample-per-minute rate. Circuit breaker and contactor trips are sampled at a rate of two per minute. This allows a margin for contact opening time before the next sample is taken. If the next sample does not show a contactor trip, it is presumed the contactor will not operate to clear the fault and alternate corrective action is immediately taken.
An exception to the nominal sampling rates is shown for the alternator feeder/source bus differential relays. The rate here is one sample per second. This is because operation of these relays results in tripping the associated alternator circuit breaker, with a consequent loss of one-half the station primary power. The sampling rate for the alternator circuit breaker is five per second, also much higher than nominal. These relatively high rates are required to minimize system and load disturbances in switching to a backup mode of operation.

A sampling rate of two per minute is chosen for detection of power conditioning equipment operating in a current-limited overload mode. Again, this allows a margin for transient overloads.

No life-critical functions have been identified for the TCD System. An unscheduled opening of the alternator feeder circuit breaker, however, results in loss of one-half of the primary power source and is therefore listed as a caution function. Loss of 260 Vdc bus voltage is also listed since this results in interruption of all 400 Hz power. Loss of 400 Hz square wave bus voltage and loss of 400 Hz sine wave bus voltage are included since they result in interruption of all 400 Hz square wave and sine wave power, respectively.

6.1.6.2.2 Periodic Checkout

Periodic checkouts will be performed at intervals ranging from once per week to once each six months depending on equipment or parameters to be checked.

The principal tests required to ensure TCD System performance, integrity, and availability are listed in Table 6-3. In addition to these tests, checks of selective switch positions, interlocks, system load distribution, and availability of load bank equipment are required. Tests for relay, circuit breaker, and contactor operations can generally be accomplished on line during periods of relatively low-scheduled experiment activity; system switching effects will be minimal. No major shock producing tests, such as power line faults or fault clearing, are planned.

Complexity of checkout varies from simple readouts of parameters, such as voltage or temperature, to injection of test currents into current transformer loop circuits to simulate fault conditions seen by protection relays. An example of a procedure which typifies the range of parameter testing and also illustrates the handling of redundant units is given in Table 6-4 for the high voltage rectifier-regulators.

6.1.6.2.3 Calibration

No requirements for calibration are listed. A limited amount of calibration may be required for certain relay installations. This has not been analyzed at this time.

6.1.6.2.4 Trend Analysis

A limited amount of trend analysis is necessary for TCD parameters. These are identified in Appendix I-7.

Table 6-3. Transmission Conditioning and Distribution System Periodic Tests (Isotope/Brayton)

Test	Rationale
Protective Relay Operation	To verify proper operation of protective devices
Circuit Breaker and Contactor Operation	To determine remote operability of breakers and contactors
Standby Redundant Equipment Operation	To verify operational capability of standby units
Battery Charger Mode Switching	To determine charger response to control inputs
Alternator Load Sharing	To determine whether load balance is within allowable tolerances
Regulated Transformer-Rectifier Load Sharing	To determine whether load balance is within allowable tolerances
Power Conditioning Equipment Parameters	To determine nominal performance capability and degradation, if any, with respect to like units
Bus Voltages	To assess general health of TCD system
Battery Monitor Voltage and Temperature	To determine battery status

6.1.6.2.5 Fault Isolation

Control signals for opening and closing remotely operable circuit breakers, contactors, and switches are required for fault isolation. These signals are operated internal to the TCD System (e.g., differential protection sensing and relay output) to provide coordinated automatic fault clearing, and external to the system for checkout purposes. A typical fault isolation flow diagram is given in Figure 6-7.

6.1.7 DATA MANAGEMENT SUBSYSTEM

Prior to defining specific tests, it is necessary to define the operating environment. It is a requirement that testing be performed on-line and that fault isolation to the LRU should be achieved to support a remove-and-replace maintenance philosophy. Operating on-line means that the testing performed must be

Table 6-4. Periodic Checkout High Voltage Rectifier-Regulators

1. Apply primary power to one off-line redundant unit.
2. Monitor open-circuit output voltage level.
3. Apply overload test current to secondary of current limiting sensing circuit and monitor for current limiting mode alarm.
4. Remove test current and reset current limiting mode alarm circuit.
5. Repeat steps 1 - 4 with second off-line redundant unit.
6. Connect first off-line unit to 260 Vdc bus and verify that input current, output current, and output voltage are within specified limits.
7. Repeat step 6 with second off-line unit.
8. Verify that the two units share load within specified limits.
9. Disconnect the two previously on-line units and assign them to the standby redundant mode.
10. Reverify load sharing between the two on-line units.
11. Continue operation with the new unit assignments until the next checkout period or until reconfiguration is required for other operational reasons.

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interleaved with other application programs. Within these constraints, it is necessary to define:

(a) The provisions included to detect errors in data transfer on a continuous basis

(b) The specific actions to be taken when errors occur within individual DMS equipment

(c) The provisions included for verifying equipment operation on a periodic basis

(d) The provisions included for reverifying equipment subsequent to a repair

(e) The OCS/crew interface with regard to equipment status information and maintenance

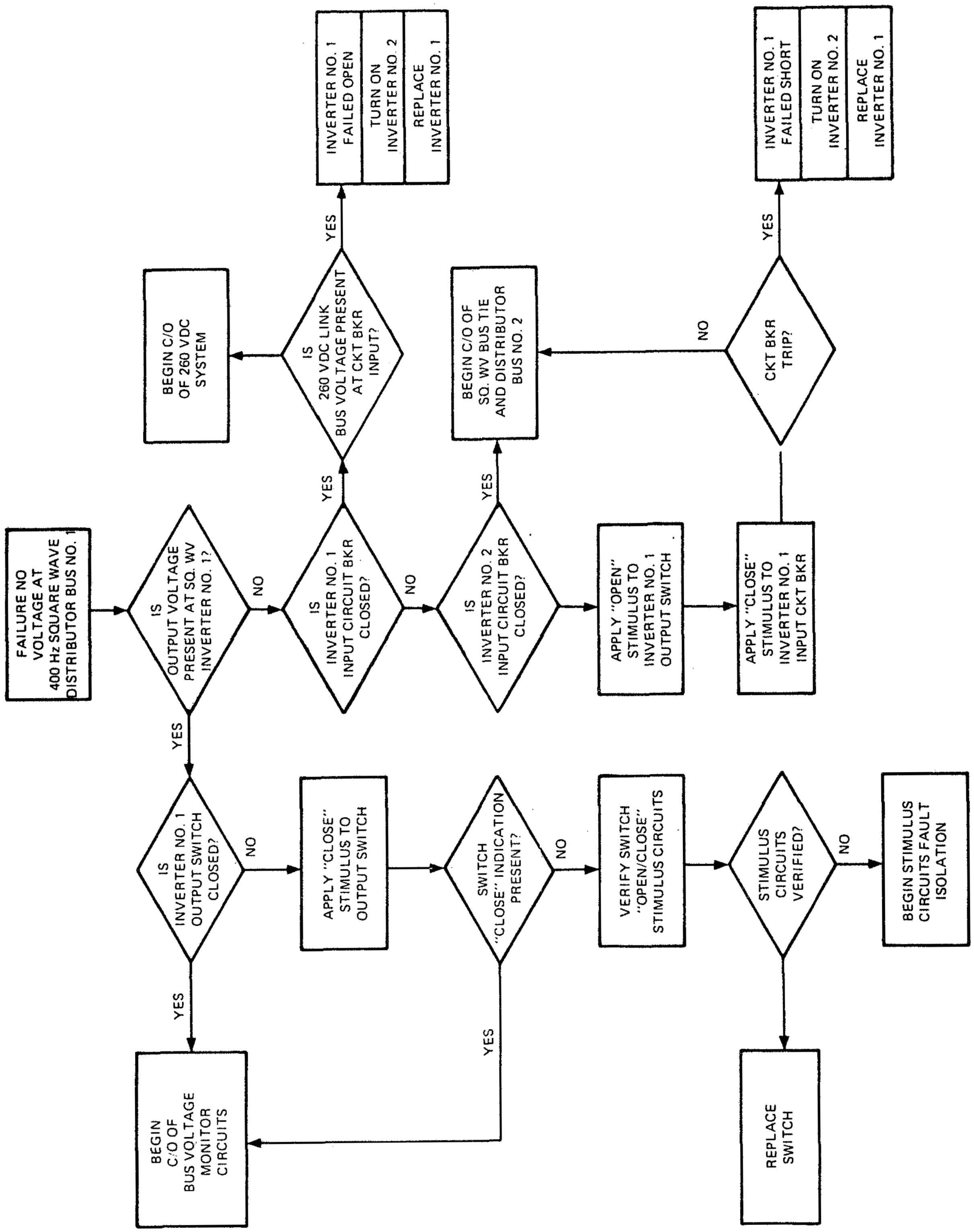


Figure 6-7. Typical Fault Isolation Flow Diagram

The constraint of operating on-line indicates that overall operation must occur somewhat as indicated in Figure 6-8. Concurrently with the execution of Operations and Experiment programs, the OCS programs will be implemented on a time available basis. During each of the time slots, certain portions of the OCS responsibility must be performed. Test sequencing and control will be performed by an OCS executive while overall time scheduling will be performed by the DMS executive. The execution of the tests will be asynchronous, and the time allocated will depend on the time demands of other programs.

Parity checking of all data transfer will occur during operation of all application programs. This is not sufficient to verify complete operation of the DMS - additional tests are required on functional areas on a scheduled basis during the time slots allocated to OCS. These additional tests must be short enough to be incorporated in the time slots, yet thorough enough to verify operation of the equipment under test. Parity errors, depending on the source, will prompt the running of some of the DMS tests to verify the error (see Figure 6-8). Other subsystems are polled as shown. These tests have been termed "Continuous Orbital Monitoring" tests (COM). The operation described above will be an iterative process - repeating after one complete subsystems test cycle. The tests performed during the COM tests, however, may not be sufficient to isolate an error or failure. It is anticipated that more extensive testing will be required on the DMS to isolate the failure to a reconfigurable element (e.g., the testing of all interfaces after LRU replacement). The second level of testing has been termed "Subsystem Fault Isolation" (SFI) tests.

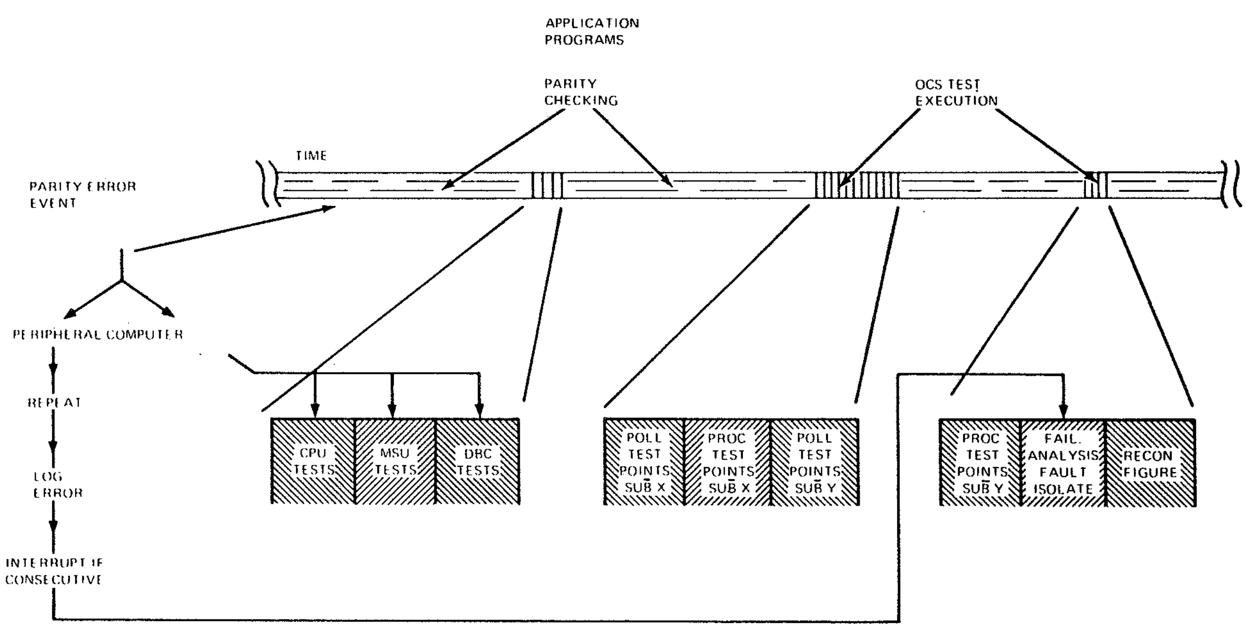


Figure 6-8. OCS Test Program Execution

Within the DMS, errors can be generated from two sources; i. e. from parity errors in any of the data transfer paths or from the COM diagnostics performed on a periodic basis. Central processing unit, main memory, or I/O parity errors will cause the appropriate COM tests to be performed to verify the error. If the error is verified, the SFI tests may be performed to isolate the fault and reconfigure the DMS to restore operation. Errors generated by the COM tests may automatically cause the appropriate SFI tests to be executed or may notify the crew to manually initiate the SFI test.

Bulk memory errors or data acquisition errors may trigger the SFI tests directly. The figure also indicates that crew keyboard entry can initiate the SFI tests. These principally are those tests which may be performed asynchronously, tests performed upon demand, or those tests which may require crew participation.

Other events can be generated by out-of-tolerance conditions emanating from measurements made on subsystem test points. Some additional processing associated with failure analysis may be required for these cases. Figure 6-9 shows a top level flow of a typical failure event analysis. If an out-of-tolerance condition occurs, it should be determined whether or not the event is associated with a critical signal. Subsequent to this, it is important to know the failure history of the function (i. e., whether it is the first or second failure). Other items include determining the source of the event indication. If it is from BITE equipment within a given subsystem, there is no alternative but to believe the indication and execute the predetermined action. If the indication emanates from an RDAU, it is possible to verify the event through an alternate path. Each of these decisions can have two results, and all paths must be analyzed. An OCS test control hierarchy that incorporates the separate responsibilities discussed above is shown in Figure 6-10. The SFI group includes the failure event analysis, fault isolation, equipment reconfiguration sequence, and display/record messages.

6. 1. 7. 1 Continuous Orbital Monitoring Tests (COM)

The COM tests associated with the DMS are divided into three groups; i. e., one group contains software diagnostics only; another group includes the acquisition and limit checking of test point data (through RDAUs), and the third group includes the parity checking hardware. Figure 6-11 shows a representative top level flow for the COM tests. These tests will not be performed without interruption as shown, but rather will be performed on a time available basis under executive control.

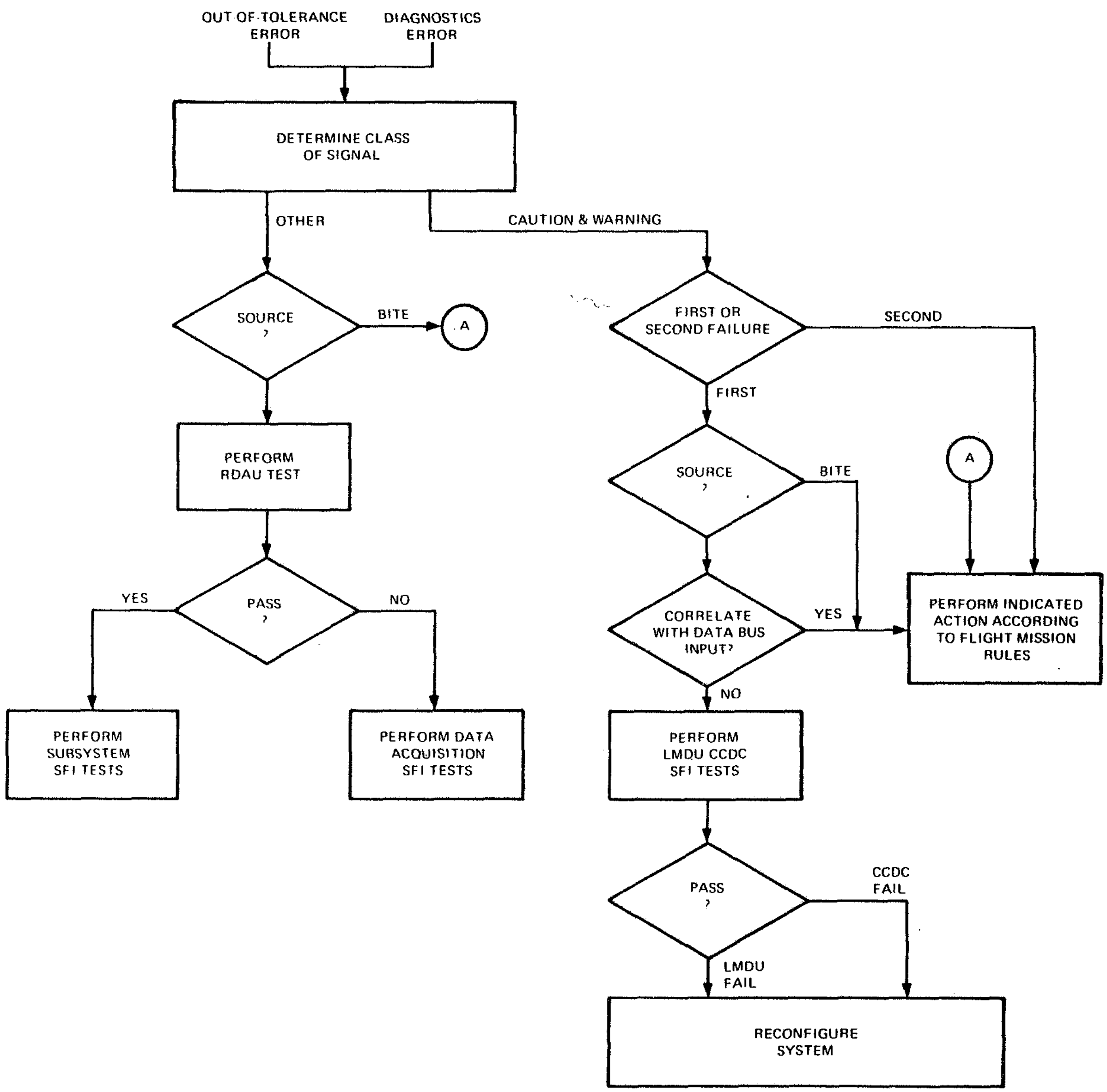


Figure 6-9. Failure Event Analysis

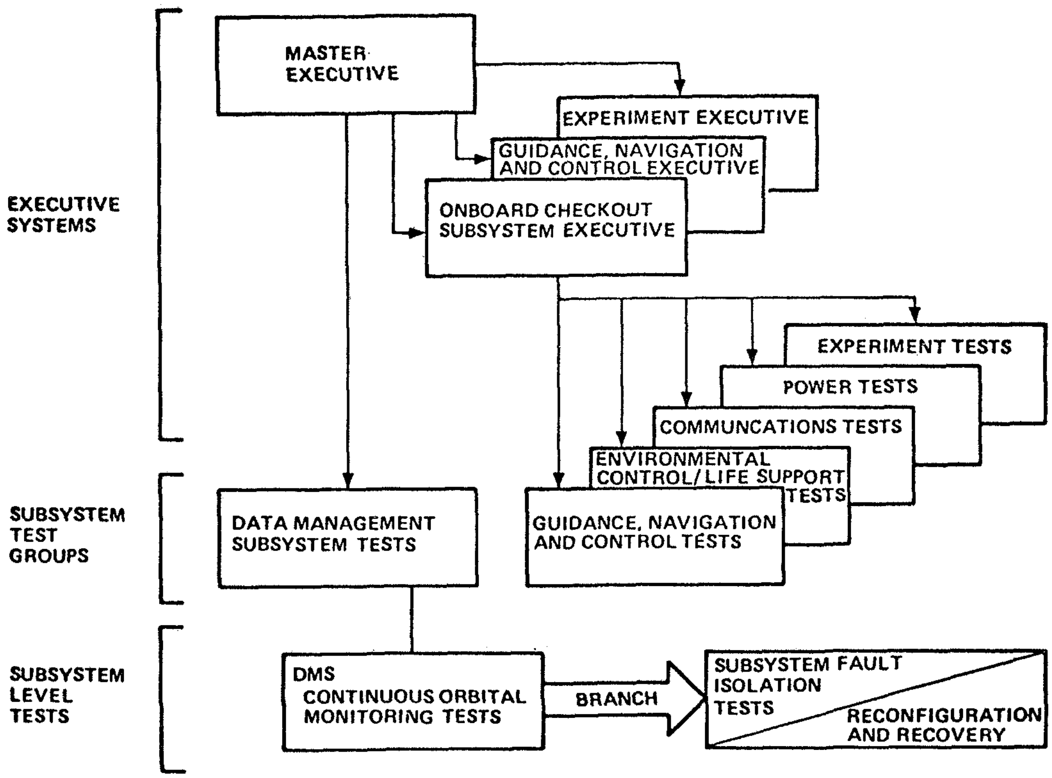


Figure 6-10. Test Control Hierarchy

6.1.7.1.1 Computer Group

The purpose of the computer COM tests is to exercise periodically as much of the central processing units, main store units, and data bus control units as possible within time constraints and without causing interference to other application programs. The COM tests shall verify capability of the following elements of the computer group:

- CPU instruction operation (i.e., add, subtract, multiply, divide, etc.)
- CPU data flow
- Register, adder, shifter, and mover functions
- Main storage addressing
- Control communication between CPU and data bus controller
- Data flow between data bus controller and main memory
- Power supplies

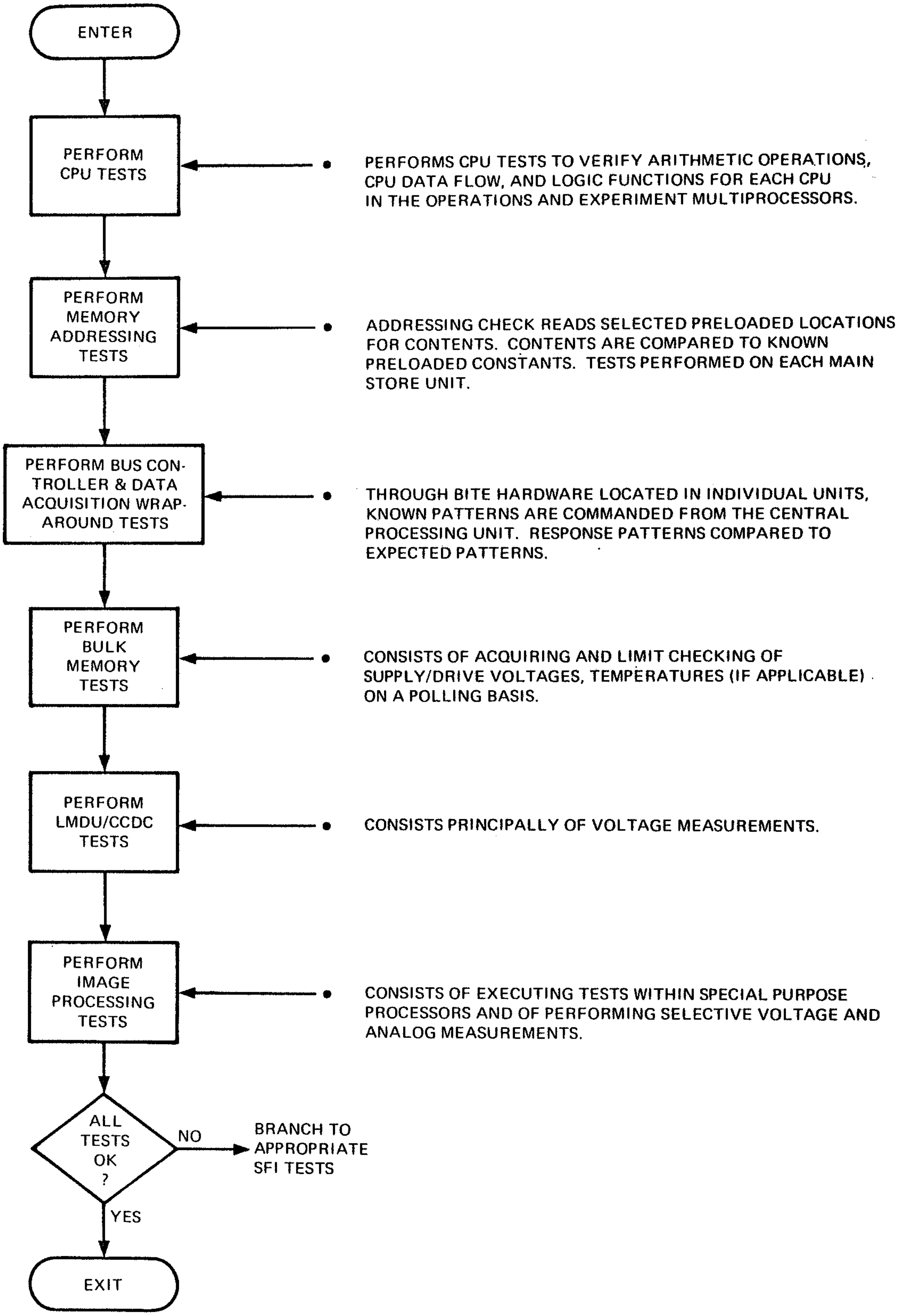


Figure 6-11. COM Top Level Flow

The CPU tests must be designed to test all arithmetic and logic functions of the computer. The basic technique to be employed will be one of performance of an operation and comparison of the actual results with the expected results. These tests must be repeated on a scheduled basis in all six CPUs.

A limited MSU test will be accomplished by main storage addressing. The test shall verify the addressability of individual MSUs by cycling through all MSU addresses on a time available basis. This test need not be repeated for each CPU test.

The COM tests also shall provide a functional check of the data bus controller by a wraparound technique, using BITE hardware. This hardware will effectively connect the bus controller output, address, and control lines to corresponding input lines. The basic technique again is to compare actual results to expected results.

In addition to these tests, power supply voltages and discrete indicators will be polled through RDAUs for comparison or limit checking. As a general rule, two consecutive errors or an out-of-tolerance measurement is caused for a subsystem reconfiguration.

6.1.7.1.2 Bulk Memory Group

The principal COM tests on bulk memory will be supply voltage measurements. All data which is transferred to or from bulk memory is parity checked, and will be the principal source of error detection. Consecutive errors will initiate Subsystem Fault Isolation Tests.

6.1.7.1.3 Data Acquisition Group

This group consists of the terminals, RDAUs, and stimulus generation units. The wraparound technique will be utilized on a periodic basis to verify the operability of each terminal, RDAU, and SGU.

6.1.7.1.4 Command, Control, and Display Group

6.1.7.1.4.1 Command, Control Display Consoles (CCDC) - The CCDC COM tests will consist primarily of supply voltage measurements. The displays and controls are subjected to testing through normal daily equipment usage. Such items as loss of character generation, display quality, brightness, etc., are self-annunciating, and special tests need not be mechanized. Crew participation is required in most tests of CCDC (see CCDC SFI tests).

6.1.7.1.4.2 Local Monitor and Display Unit (LMDU) - The COM test for LMDUs should be implemented in a similar manner as the RDAUs; i.e., on a periodic basis, the LMDU should be utilized in a wraparound type test for response generation. The response should be compared to an expected pattern.

The display is subjected to a form of continuous orbital monitoring through crew use and observations. There will be no special COM display tests utilized on a continuous basis.

6.1.7.1.5 Image Processing Group

The COM tests for the image processing equipment will consist primarily of supply voltage and other analog measurements. Additional integral diagnostics should be included with special purpose processors such that the diagnostics can be commanded from the DMS computers. An interface with an RDAU should be provided to implement communications with the DMS computers.

6.1.7.2 Subsystem Fault Isolation Tests (SFI)

The COM tests performed on a cyclic basis and supplemented with parity checking comprise the fundamental DMS error or failure detection capability. If a failure is detected, it must be isolated to a replaceable unit. The testing capability for isolating to the replaceable unit is called "Subsystem Fault Isolation (SFI).

Since it is incumbent upon the DMS/OCS to be able to isolate failures to the line replaceable unit (LRU), a definition of these elements has been formulated. These are partially a result of the degree in which a software/hardware system can effectively isolate malfunctioning elements in addition to the physical considerations of packaging and accessibility within a given equipment complex.

Several techniques are presently used to provide varying degrees of "self checking" and fault isolation capability within computers. These techniques were investigated with respect to their applicability for the Space Station OCS. In addition to the COM tests, four fundamental techniques will be used in the proposed SFI scheme. The four include:

- Parity checking on all internal data

  Checks hardware for correct data handling capability.

- Known problem computation

  Checks hardware for correct data handling and computing capability. Test more conclusive than parity checking.

  Extract problem routine from memory, work problem, verify answer with correct answer stored in memory.

- Hardware pattern generator

  - Checks hardware for correct data handling capability.

    Generates known data word pattern for checking write/read accuracy of memories.

- Crew interactive/manual tests

6.1.7.2.1 Computer SFI Tests

For the purpose of deriving a fault isolation scheme, the DMS/OCS computer subset has been modeled as shown in Figure 6-12. This model is comprised of the following elements:

- Data bus controller (DBC)
- Data bus switch matrix (DBSM)
- Data bus input/output (DBI/O)
- Shared memory matrix (SMM)

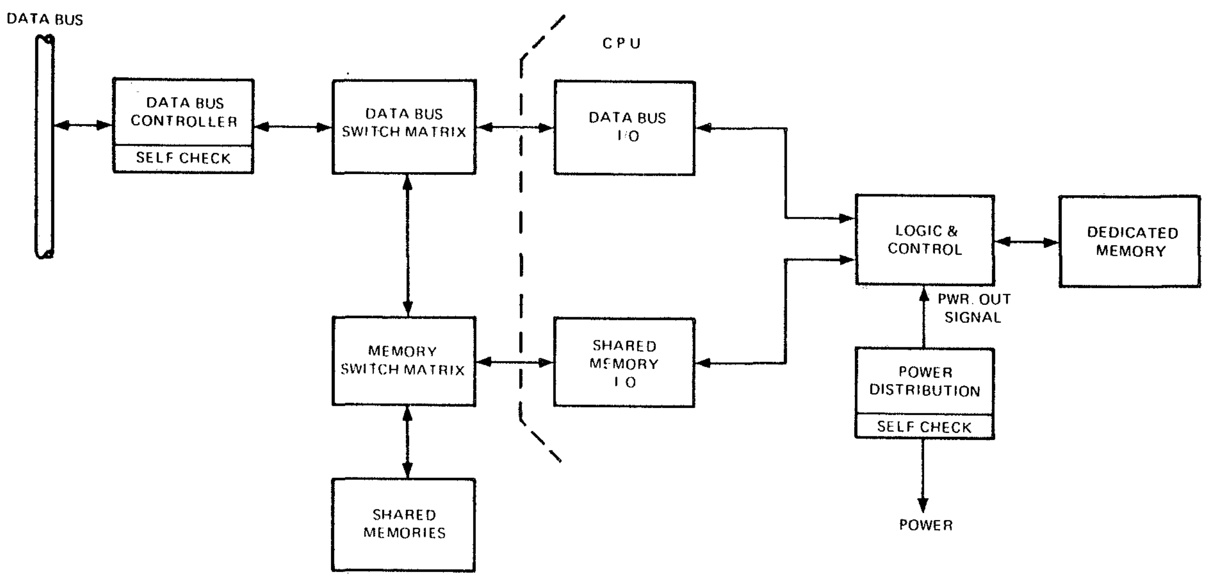


Figure 6-12. Computer Subsystem Diagnostic/Fault Isolation Model

- Shared memory
- Shared memory input/output (SMI/O)
- Logic and control (L & C)
- CPU dedicated memory
- Power supply and distribution

These elements have been described in Section 4.4, Line Replaceable Unit Definition.

Figure 6-13 depicts the proposed computer subsystem fault isolation logic developed for the DMS/OCS. The primary diagnostic conditions utilized in this scheme are:

- Detection of parity errors
- Incorrect (or no) response to a command or pattern check

The "soft power down" activity is noted in Figure 6-13 only to the extent of depicting the isolatable unit involved. By its very nature, it is self-diagnostic and isolating.

The flow diagram indicates a shared memory as an isolatable unit. By employing certain manual procedures supplemented with additional automatic (via OCS) tests, the shared memory units can be further broken down to a lower level of isolation i.e., the LRU level. Figure 6-14 gives a unified fault isolation model for the shared memory unit.

Manual diagnostic/fault isolation procedures for determination of the shared memory LRUs would be dependent upon the type of OCS notification, i.e.,

Type I - Shared memory will not respond to inquiry or command

Type II - Shared memory generating parity errors or incorrect write/ read of known pattern

Figure 6-15 depicts the manual diagnostic and fault isolation logic for the shared memories. It is postulated that the mechanical sections will have some type of self-test capability to determine operational status. This self-test capability would be manually actuated in such a manner as to demonstrate the action of various mechanical, and electro mechanical components (motors, solenoids, gears, etc.). A human operator, following a prescribed diagnostic routine, could then reasonably assess the operational status of the mechanical section.

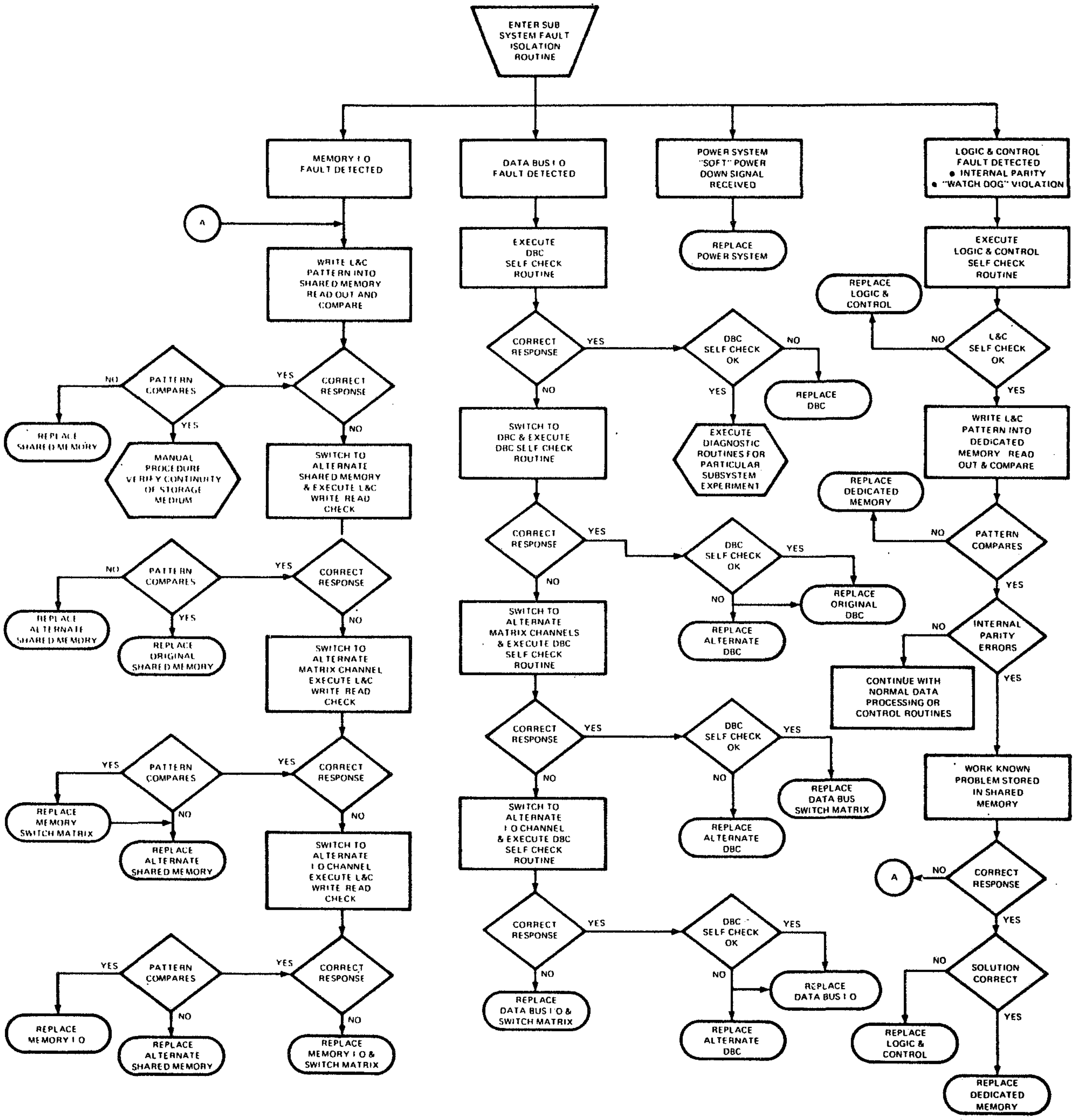


Figure 6-13. Computer Subsystem Fault Isolation Flow Diagram

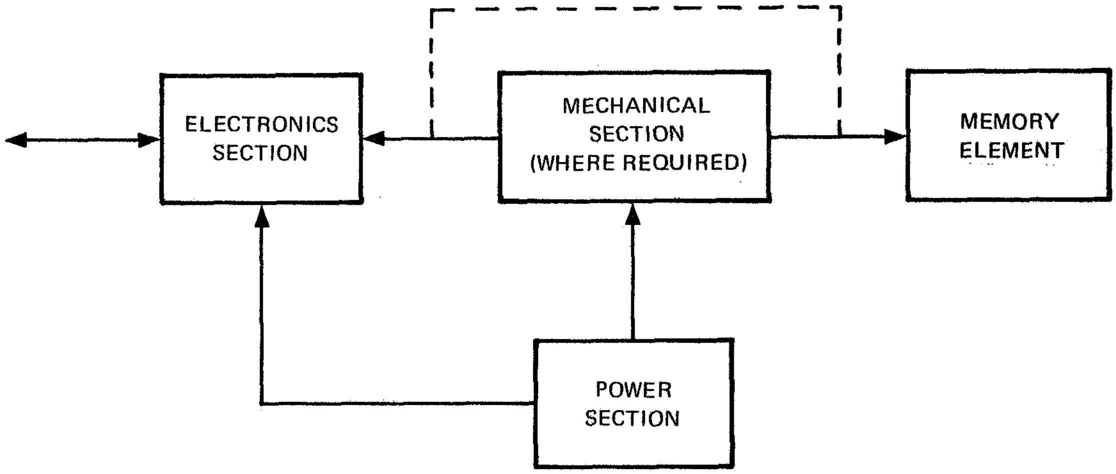


Figure 6-14. Shared Memory Unit Manual Diagnostic/Fault Isolation Model

6.1.7.2.2 Bulk Data Storage

Figure 6-16 is a diagnostic/fault isolation model for the bulk data storage facility. This model is comprised of the following elements, each of which has been described in Section 4.4, Line Replaceable Unit Definition.

- Digital Buffer and Control Unit
- Record/Reproduce Electronics
- Switch Matrices
- Tape Transport Controller
- Tape Transport
- Power Supply and Distribution Units

Figure 6-17 depicts the proposed bulk data storage fault isolation logic. The primary diagnostic conditions utilized in this scheme are the same as those noted for the computer subsystem fault isolation scheme.

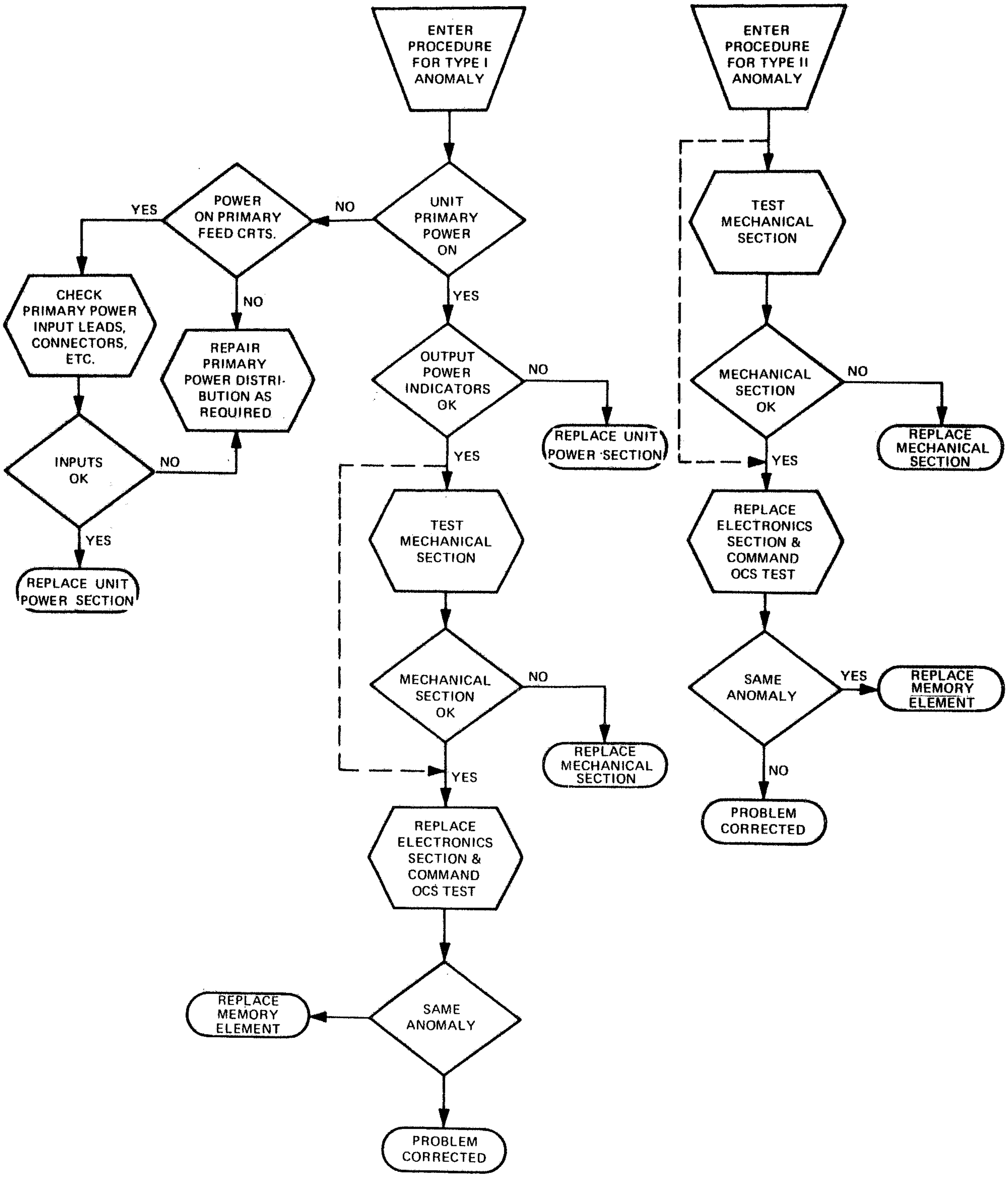


Figure 6-15. Shared Memory Fault Isolation Flow Diagram Manual Procedure

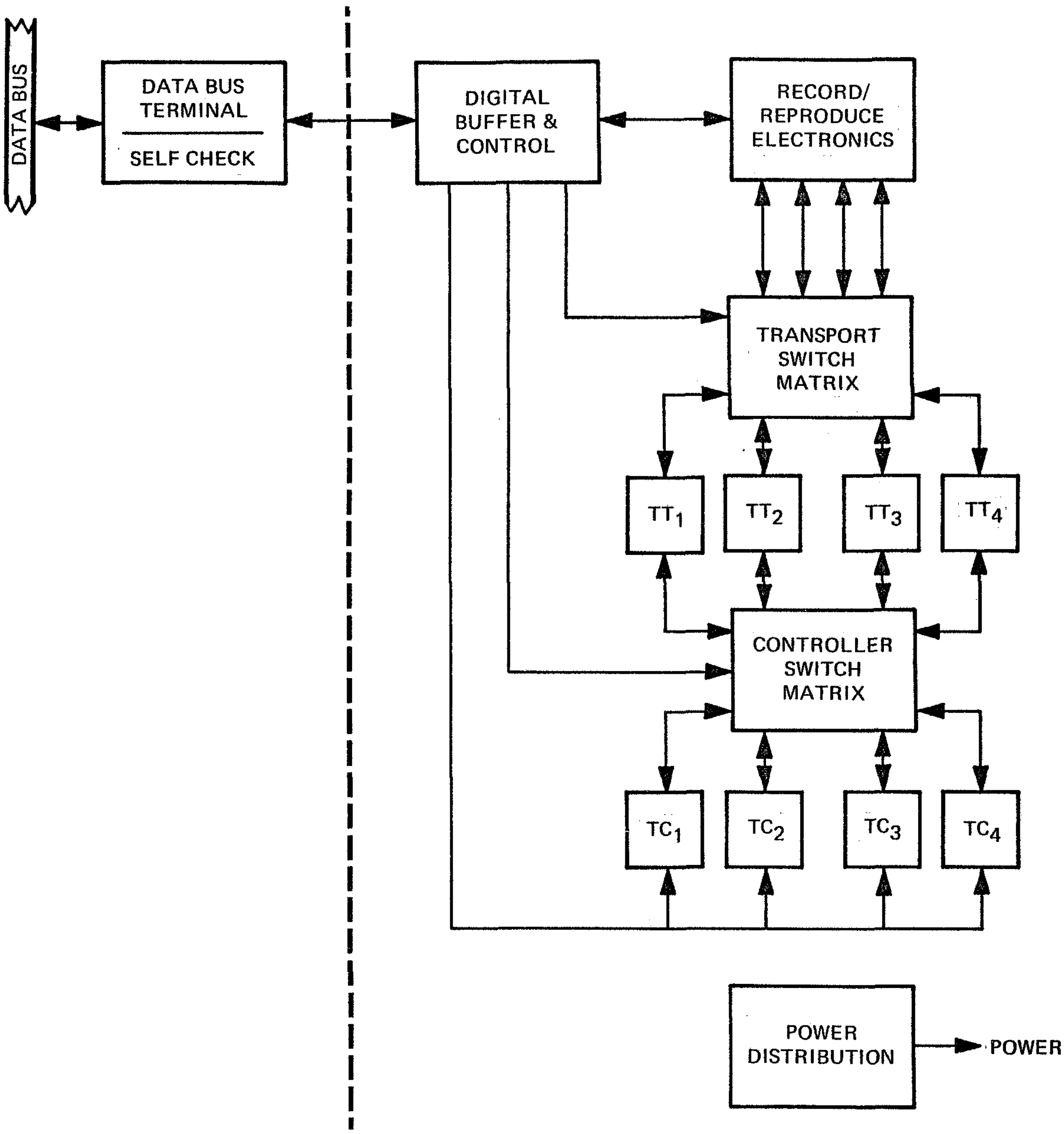


Figure 6-16. Bulk Data Storage Diagnostic/Fault Isolation Model

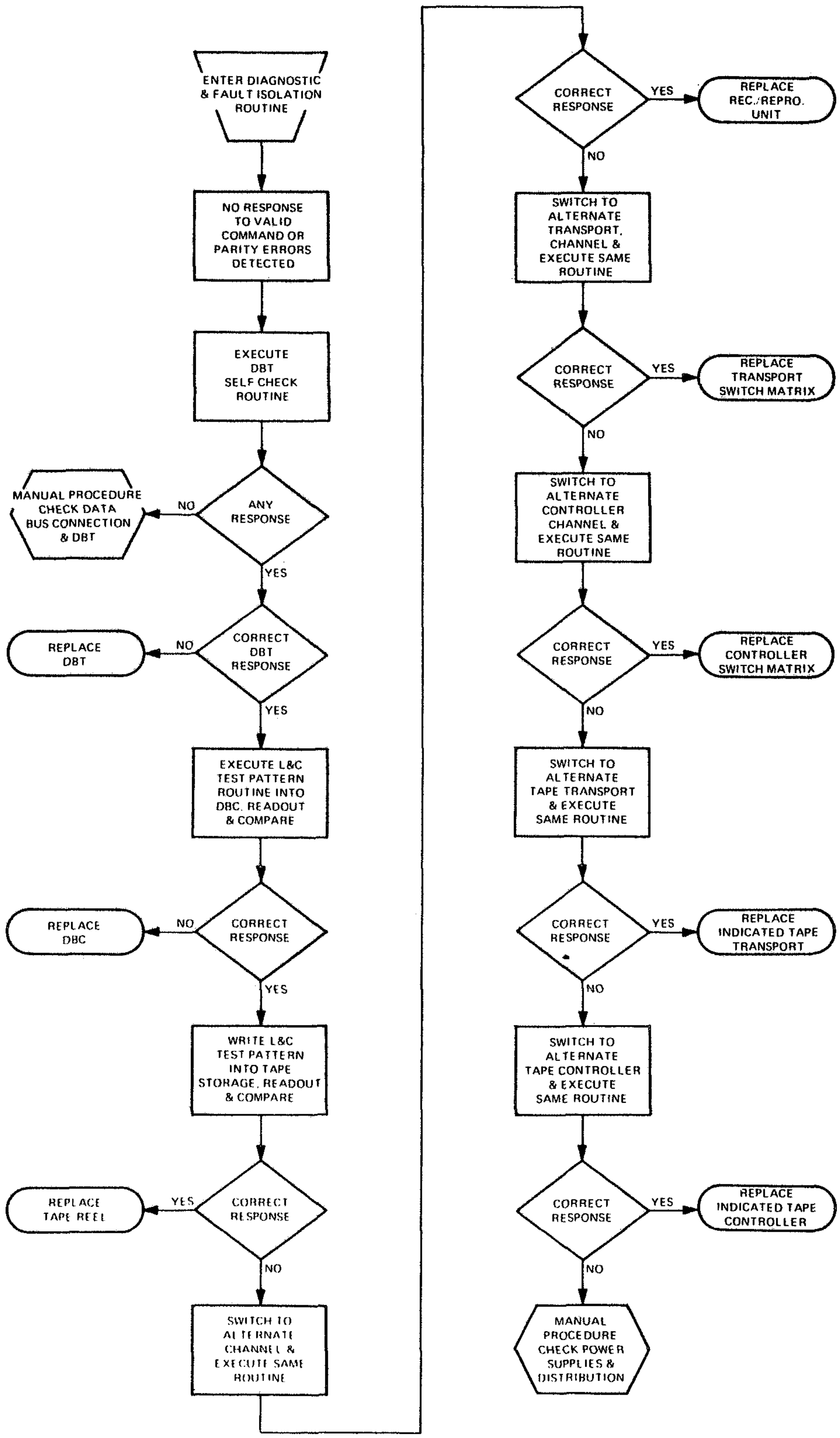


Figure 6-17. Bulk Data Storage Fault Isolation Flow Diagram

6.1.7.2.3 Data Acquisition Subsystem

A typical Data Acquisition Subsystem element is shown in Figure 6-18. This element is a representative hardware configuration for a majority of the identified data acquisition requirements on the Space Station. It is comprised of the following elements, each of which has been described in Section 4.4, Line Replaceable Unit Definition:

- Data Bus Terminal (DBT)
- Remote Data Acquisition Unit (RDAU)
- Stimuli Generation Unit (SGU)

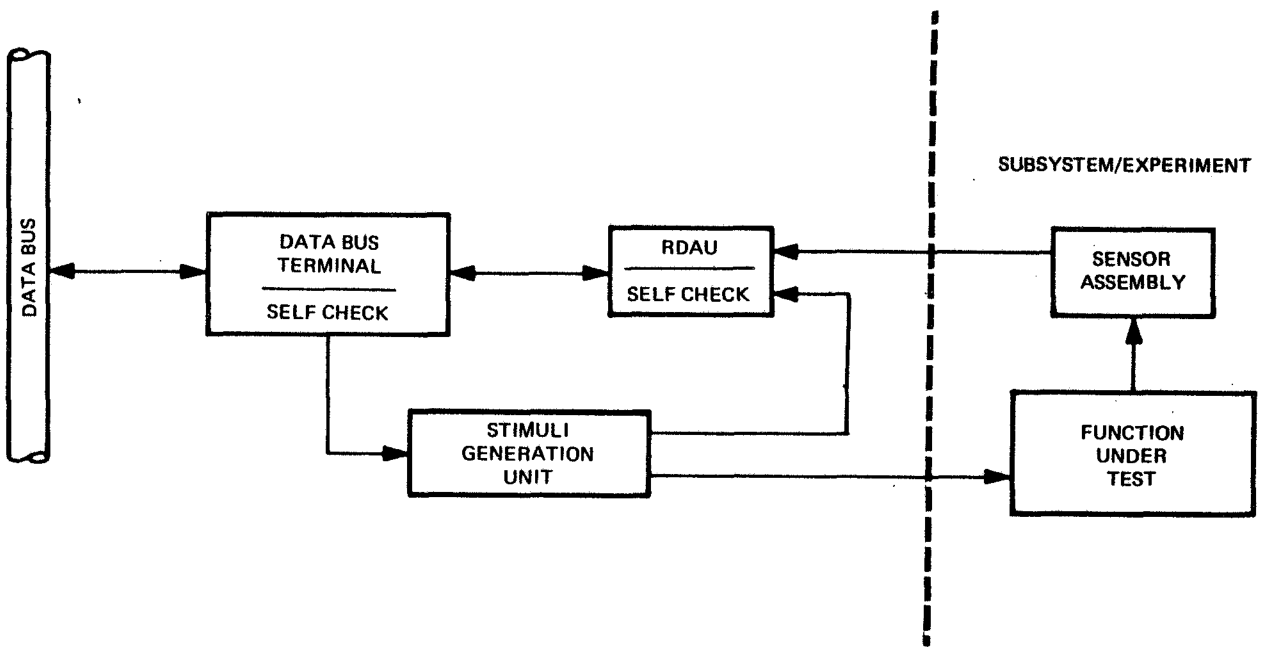


Figure 6-18. Typical Data Acquisition Element

It is incumbent upon the DMS/OCS to be able to identify malfunctioning elements to the lowest replaceable unit (LRU) in the system loop. Each of these units has the ability under DMS/OCS computer control to perform an operational self-check of its circuitry or, in the case of the SGU, to provide a special test output which can be monitored by a known "good" RDAU and thereby provide an indication as to the functional status of the SGU. Using these built-in capabilities, the DMS/OCS can, with proper programming, initiate checkout routines in such a manner as to identify LRUs and other elements which indicate fault operation. The fault isolation logic for the data acquisition elements is given in Figure 6-19.

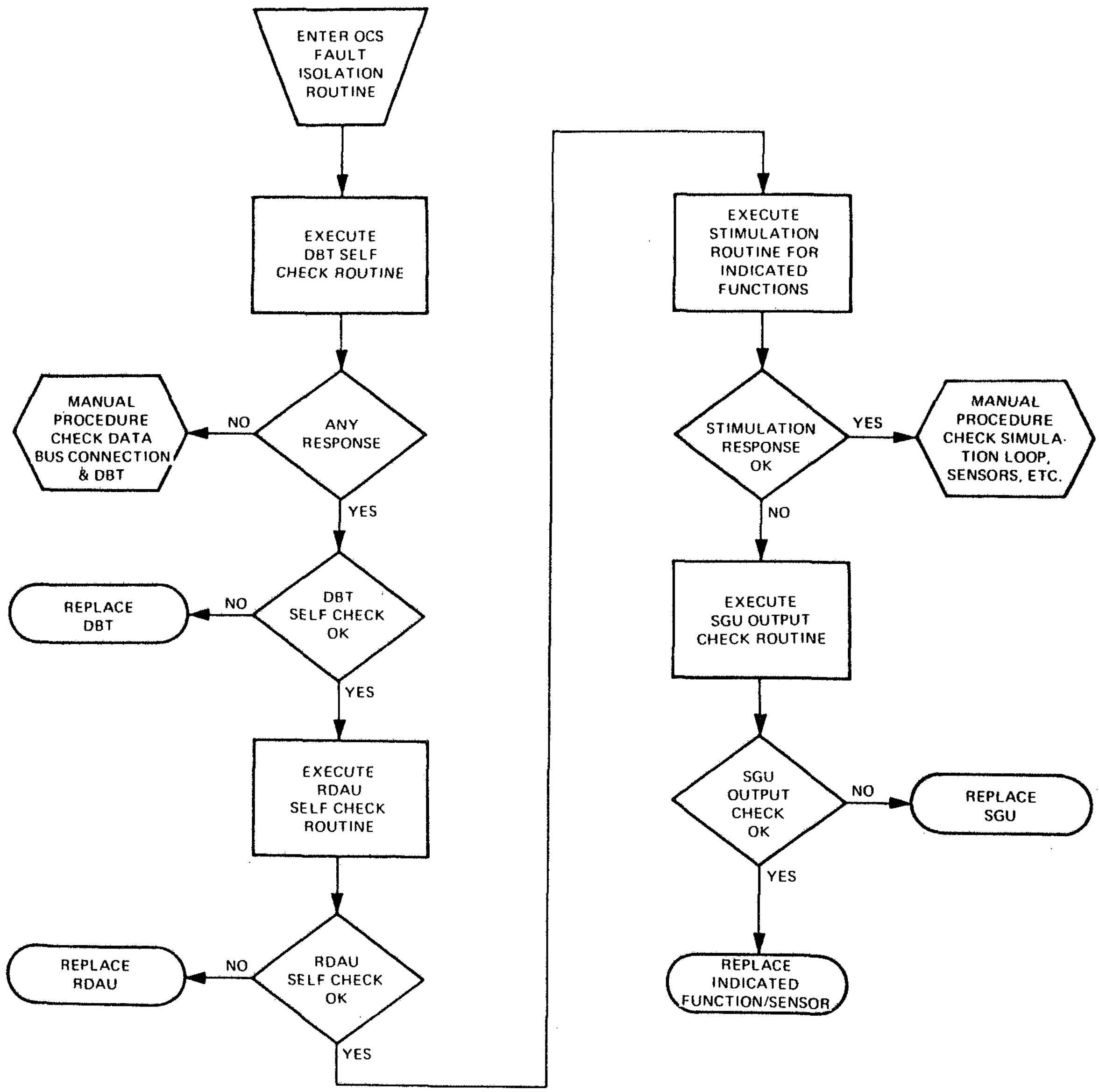


Figure 6-19. Data Acquisition Element Fault Isolation System Flow Diagram

Since the OCS ground rules do not preclude manual fault isolation activities, their use was integrated in the proposed scheme only to the extent necessary to supplement the automatic fault isolation and only in those cases where it would be extremely expensive to implement or would be impossible from a practical standpoint. The flow chart depicts two items which indicate the need for manual troubleshooting.

1. Addressed data terminal does not respond to valid commands. This indicates a possibility of a bad data terminal/data bus connection or a catastrophic data terminal failure. The possibility of a bad data bus can be investigated by checking continuity of data transmission on that particular branch.

2. Bad data is being received but the DBT and RDAU self-checks are satisfactory, and the stimulation responses are correct. This is a situation which would tend to indicate a sensor assembly/function under test which responded correctly to a calibrated input (simulation signal), but not correctly to a measured parameter input. This would, however, be a legitimate indication if the stimulation signal was inserted at points in the system different from the measured parameter input. In this case, it would indicate a fault in the portion of the system not included in the stimulation loop.

This fault isolation scheme would, with the exceptions noted above, automatically indicate which data acquisition LRU would need to be replaced. The actual replacement would then be a manual operation. The "Replace" signals could be used to switch in redundant units for noncritical parameters in addition to providing the display. For critical functions, this scheme would provide a status display only since these functions will be implemented operationally redundant.

6.1.7.2.4 Command/Control and Display Console SFI Tests

It is postulated that the individual control and display assemblies (status lights, keyboards, pushbuttons, etc.) of the Command/Control and Display Console will be respectively "unitized" and contain their own particular encode/decode electronics. For example: the computer keyboard assembly is comprised of the mechanical key assembly and all required control and encode electronics. This entire keyboard assembly could be removed, as a unit, from the CCDC. Light panels, alphanumeric displays, etc., would be handled in a similar manner. The CRT display assembly would contain the CRT, deflection circuitry, and all required video control circuitry.

Figure 6-20 shows a top level flow for the CCDC SFI tests. The tests include both automatic and manual tests. The automatic tests include those associated with the data bus terminal, command buffer and control unit, and stimulus generation unit. Tests associated with lamps, CRT displays, or viewers are manual tests.

6.1.7.2.5 Image Processing SFI Tests

As in the CCDC, image processing SFI tests will be largely manual. The automatic tests are concerned with the digital equipment interfacing the computers. Figure 6-21 shows a preliminary top level SFI flow diagram for the image processing equipment.

6.1.7.3 DMS Test Timing

Tests typical of those required for the DMS can be sized for memory and execution time, but the frequency with which the tests must be performed was not specified. In addition, certain units within the DMS probably will be checked more frequently than others. Because the aggregate contribution to computing load by the DMS/OCS depends upon these items, it is necessary to assure the frequency of performing tests and the sequence or order in which the units are checked.

The two principal factors upon which the test iteration rate could be based are the failure rates and mission criticality. Of the two factors, criticality will demand the highest iteration rate. The approach taken has been to examine the mission and to specify a maximum time during which an undetected failure can be tolerated. The cumulative time required for detecting the failure, for isolating the failure, and for recovery must be equal to or less than the total time during which the failure can be tolerated.

A moderate worst case which can be utilized as a basis for affixing the iteration rate is a docking operation. During this operation certain commands and responses are exchanged between the Space Station and the docking vehicle. Some of the considerations involved in this operation are discussed in McDonnell Douglas Space Station Electronics Subsystem Study (DRL 8, Volume 5, Book 5, pages 169-177). The primary docking mode is automatic, but with crew observation having override capability. Failures in the DMS will cause erratic or total loss of data exchange capability with the docking vehicle for a period of time. During docking, range and closing rate are important parameters involved in command maneuvers. Erratic or loss of computational capabilities may be manifested through range errors or closing rate errors. Errors which permit too rapid a closing rate can affect vehicle safety, while errors permitting too slow an approach expend docking vehicle fuel unnecessarily.

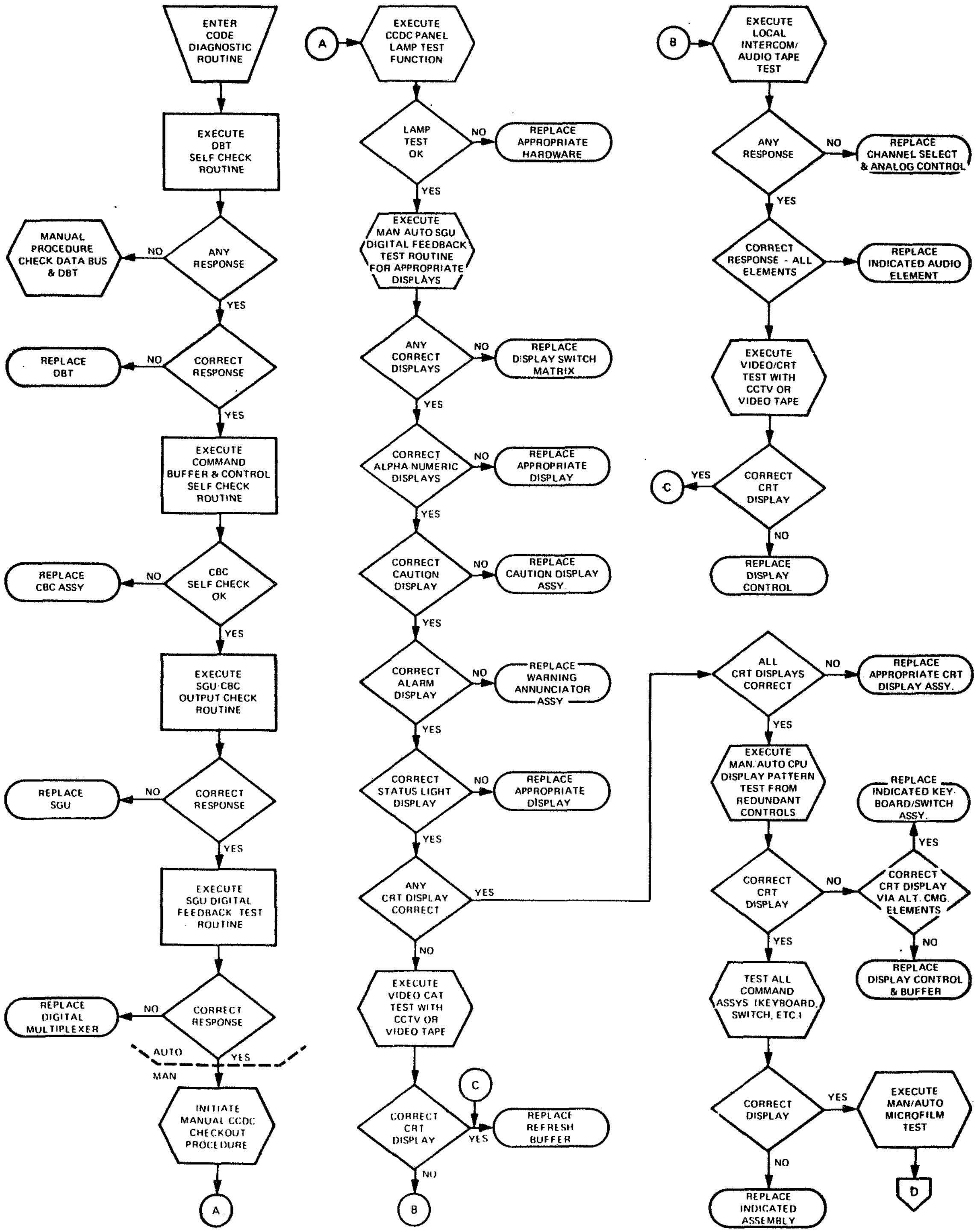


Figure 6-20. Command/Control and Display Console Fault Isolation Flow Diagram

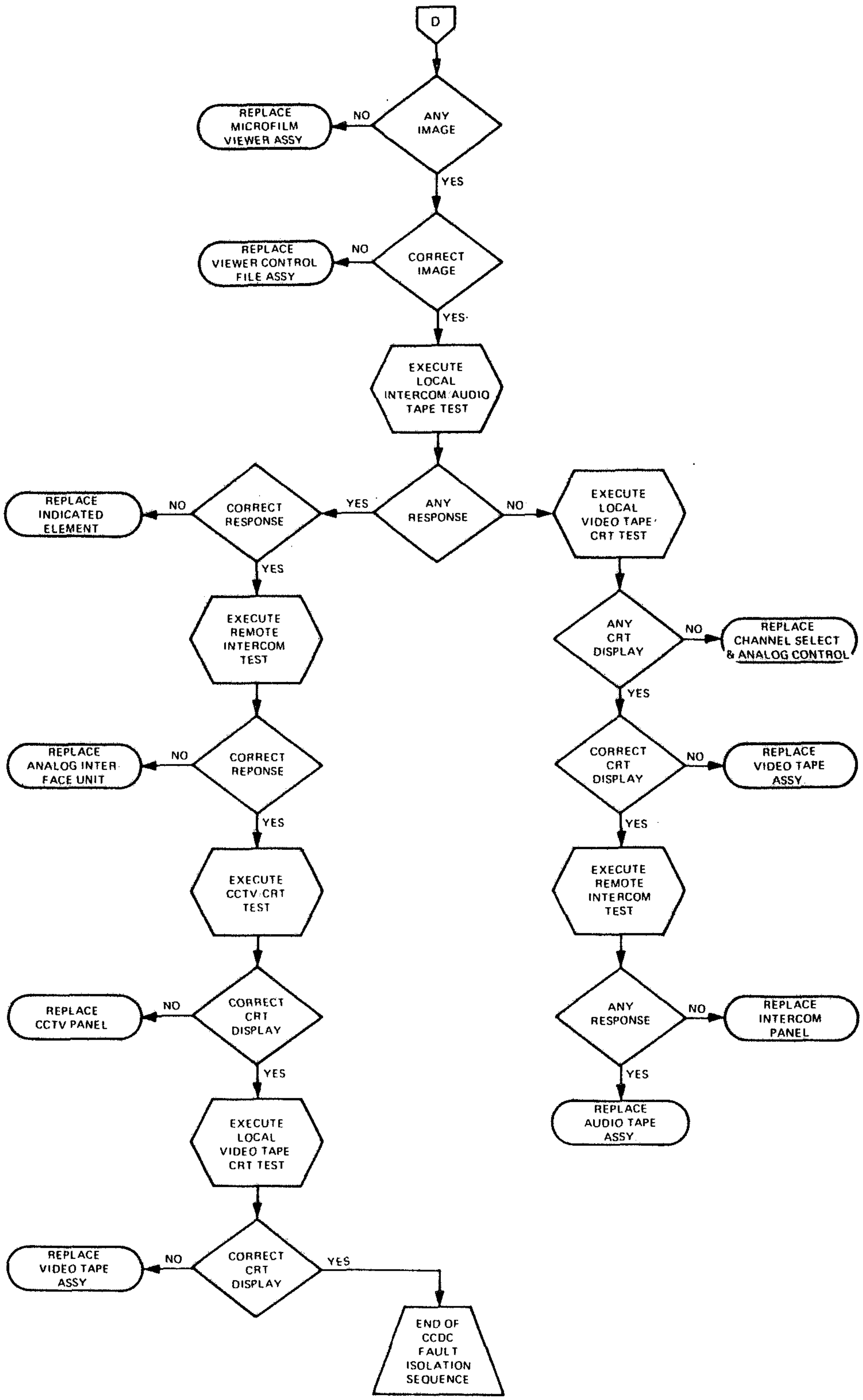


Figure 6-20. Command/Control and Display Console Fault Isolation Flow Diagram (cont)

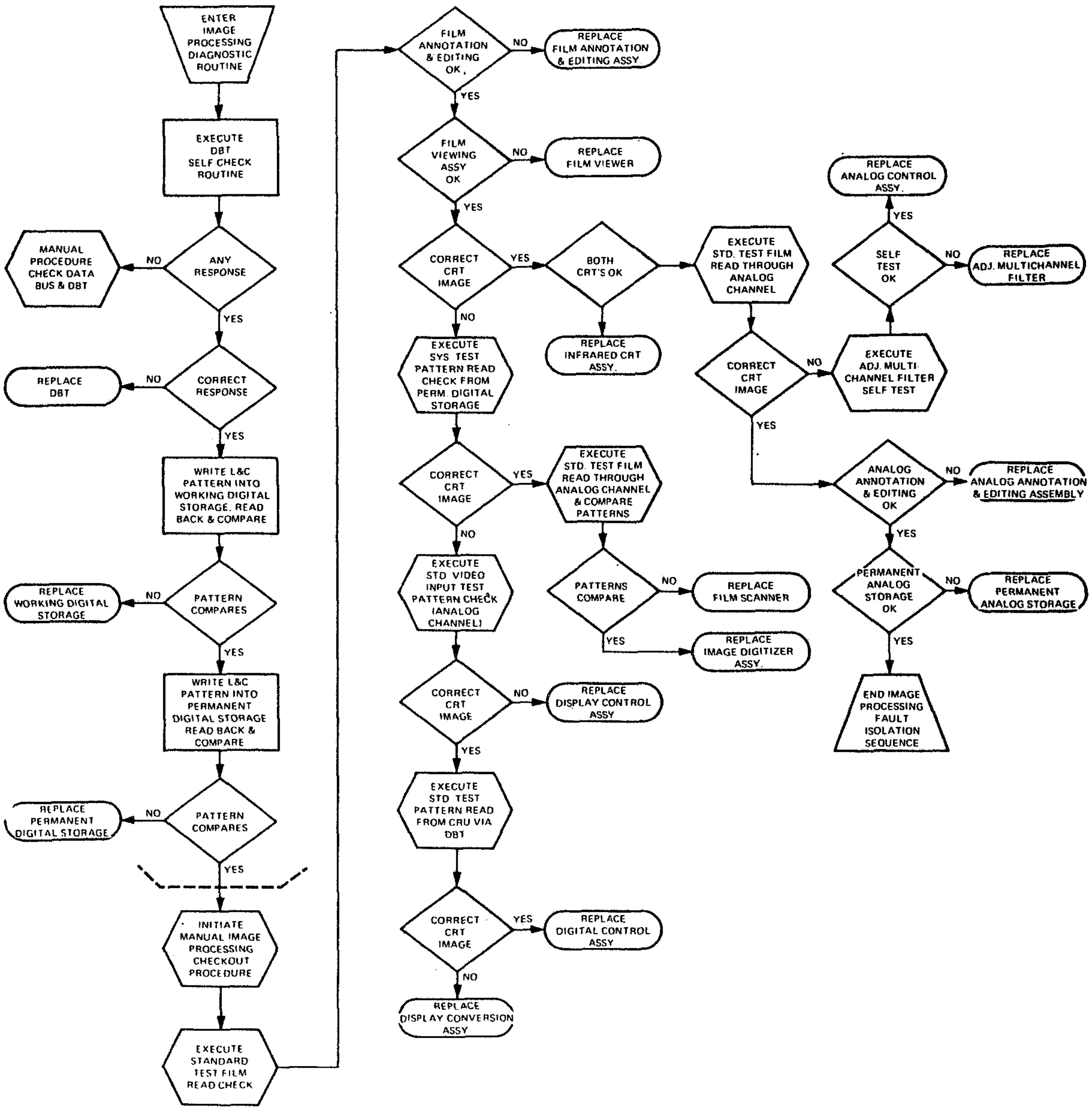


Figure 6-21. Image Processing Fault Isolation Flow Diagram

For anlaysis purposes, it was assumed that the maximum allowable error build-up in closing rate is 10 percent (i.e., due to DMS failure to deliver or remove some command). At one foot per second in the near vicinity of the Space Station, the maximum allowable error would be 0.1 foot per second. If a 100-pound thruster were left "ON" due to a failure, the time required to produce a 0.1 foot/sec velocity increase towards the Space Station would be (assuming a 40,000 pound vehicle):

$$t = \frac{V}{aac.} = \frac{\frac{0.1}{100}}{40,000} = 40 \text{ seconds}$$

If it is assumed further that any errors imparted to the system must be removed upon recovery, the tests must be performed in one half the time above or 20 seconds. Therefore, an iteration rate of once per twenty seconds was utilized for sizing the software for checkout of that DMS equipment involved in the critical operation.

The DMS equipment appears to fall into four categories with regard to the frequency of testing. The first group is a critical group consisting of the CPUs, main memory units, data bus controllers, critical terminals, and critical RDAUs. This group is tested once per 20 seconds in accordance with the postulated worst case situation. The second group is less critical, and consists primarily of the remaining terminals and RDAUs. The second group should be checked at least once per hour, and will also contain all discrete and analog measurements to be made on DMS equipment (e.g., power supplies).

The third group consists primarily of bulk and mass memories and displays. This group should be checked at least once per 24 hours. The fourth group will be an "on-demand" group associated with image processing, repair verification, calibration, etc. Table 6-5 summarizes the iteration periods.

6.1.7.4 DMS Measurements/Stimuli

In addition to the software programs and BITE provisions, a series of measurements must be made on certain DMS equipment. The measurements will be concerned principally with power supply measurements and temperature measurements.

Each supply contains certain protective circuitry associated with over-voltage, under-voltage, and over-current protection. Each supply should provide a discrete logic output indicating that a limit has been exceeded. The logic output would be monitored via an RDAU.

Table 6-5. Iteration Periods

1/20 sec.	1/hour	1/24 Hours	On-Demand
COM tests		SFI Tests	
1. CPUs	1. All DMS Measurements	1. Bulk and mass memories	1. Image Processing
2. MSUs	2. Noncritical Terminals and RDAUs	2. Standard Display Patterns • CCDC • LMDU	2. Calibration
3. DBCs	3. SGUs		3. SFI Tests
4. Critical DBTs			4. Repair Verification
5. Critical RDAUs			
6. Measurements Associated with above LRUs			

Temperature measurements will be checked on equipment likely to require monitoring. The measurements will be made on the racks through which the coolant will flow. Actual measurement will be performed and limit checked within the RDAUs.

Appendix I-9 lists the measurements and stimuli required to complete checkout of the DMS.

6.1.7.5 DMS Test Software Sizing Study

The approach taken in the study was to implement the Command SFI tests previously described to estimate the DMS resources required to perform the tests. Flow charts were generated to describe the logic for each test. Accompanying each test flow is an estimate of the memory required, the CPU time required to execute, and the I/O time required if applicable.

Because software sizing is very much involved with the basic organization of the processing equipment, it was necessary to expand considerably the baseline DMS to assume additional architectural features. Many of the assumed features were with regard to:

- Processor interrupt features and instruction capabilities
- How processor-to-processor communications are implemented to convey CPU failure data to other CPUs
- How main memory is organized with regard to addressing, memory contents, table formats, preferential storage areas, etc.
- How the I/O channels are assumed to operate
- The channel command word format
- How information tables are stored with regard to configuration control
- How out-of-tolerance conditions propagate through the data acquisition path

Certain of the features above are key to OCS software sizing of DMS tests while other features may be more important to executive control of OCS and general software design. Most of the features assumed have been utilized in one or more applications for similar purposes (e.g., in the IBM System/4 Pi and IBM System/360 lines).

6.1.7.5.1 Architectural Assumptions

6.1.7.5.1.1 Microprogram - The processor can be microprogrammed so that the basic instruction set can be augmented without requiring an engineering change to the processor. The need for such augmentation arises from the requirement to automatically test, isolate, and reconfigure the DMS hardware under software control. An example of this type of instruction is the one used to set the address translation register of a shared memory LRU.

It is also assumed that the processor contains special reconfiguration instructions (e.g., "set configuration control registers"). Configuration control registers within each configurable element will be the principal means of maintaining configuration control.

6.1.7.5.1.2 Interrupts - An Interrupt System exists to provide a means by which a computer can make rapid response to extra-program circumstances that occur at arbitrary times and perform a maximum amount of useful work while waiting for such circumstances. Parity errors, failures, or out-of-tolerance conditions will result in an "interrupt." The types of interrupts assumed include:

- "Machine Check" interrupt is provided in the event of machine malfunctions (e.g., failures in processors, memories, or data bus controllers).

- "I/O" interrupts are provided as a means whereby a CPU will respond to a request from an external device. Out-of-tolerance conditions as indicated via RDAU limit checking will cause an I/O interrupt.

- "Program" interrupts to denote improper specification or use of instructions and/or data .

- "Supervisor Call" interrupt to implement a high speed request for executive services (e.g., task switching, storage allocation, data logging, configuration control register management, etc.).

- "External" interrupts for miscellaneous purposes (e.g., to enable a response to timers, crew console keys, and processor-to-processor communications).

6.1.7.5.1.3 Parity - Parity checking will be utilized to provide a continuous checkout of all data transfer to and from the processors. Parity errors in general will result in a machine check interrupt.

6.1.7.5.1.4 Processor-to-Processor Communications - Processor-to-processor communications exist to permit the asynchronous transfer of data pertinent to reconfiguration to other processors. Actual communication will be implemented through the data bus controllers rather than through a direct interface (avoids the case where each processor must "pass along" information regarding other processor conditions).

6.1.7.5.1.5 Configuration Control Capability - A "configuration control register" will be maintained in each DMS configurable element to establish the prevailing subsystem structure by specifying to each element its state, the processors from which it accepts configuration changes, and the elements to which it listens in the exchange of data and certain control signals. The operational processors will have the capability of examining and setting all configuration control registers for system configuration data.

6.1.7.5.1.6 Real-Time Clock - A "real-time" clock is required to keep a copy of the reference clock (reference clock is external to the processor). It is included in the processor to allow high speed reference to real time.

6.1.7.5.1.7 Interval Timer - A high resolution interval timer is included for storage of the interval remaining until a time dependent event must be initiated. When the interval elapses, an interrupt occurs such that high frequency polling of a clock is not necessary.

6.1.7.5.1.8 Storage Address Translation Capability - Storage address translation capability exists to facilitate the interchange and reconfiguration of main memory elements.

6.1.7.5.1.9 Use of Dedicated Memory - The dedicated memory associated with each processor will be used as a buffer which is not addressable by a program, but rather is employed by the processor to contain those portions of main storage currently being used. When the program starts operating on data in a different portion of main storage, the data in that portion is loaded by the processor into the buffer and the data from some other portion removed. This activity takes place without program assistance and is completely transparent to any program instruction.

The main storage organization as seen by each processor is as follows:

- Define Pi, i = 1, 2, 3, . . . as the preferential storage LRU associated with each processor. See Figure 6-22.

- Each processor "sees" the first LRU of addressable memory as the LRU containing its own preferential storage area (PSA).

- Beginning with the highest address expressable in 24 bits (4000 K words) and proceeding downward, each processor has the hardware capability to assess the preferential storage areas of other processors, for fault isolation and reconfiguration purposes. Authorization is under software control.

This arrangement allows for expanding the number of processors and the amount of main storage without disturbing the addressing scheme.

A special instruction is available to set the PSA base address (e.g., as in the IBM/FAA 9020 system) thus allowing the PSA to be in shared, instead of dedicated, memory.

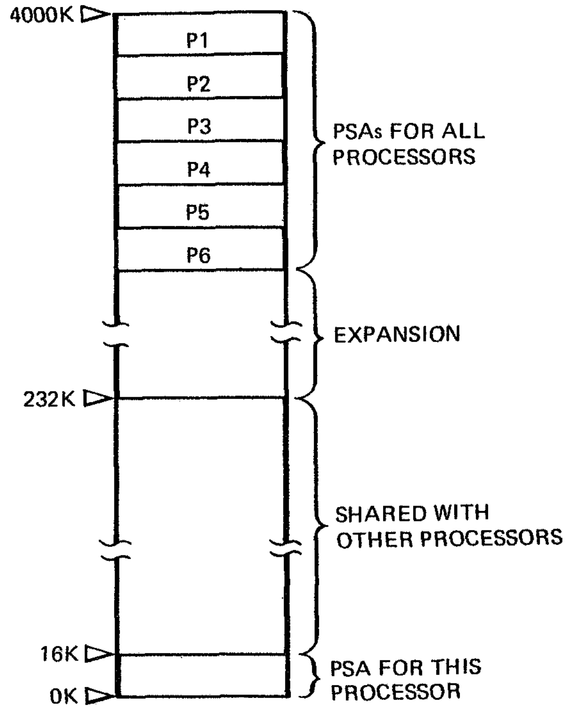


Figure 6-22. Main Storage Organization Seen By Processor

6.1.7.5.1.10 Processor-to-Memory Communications - It is fundamentally necessary for OCS purposes for any processor to access any other processor PSA because it is in this area that data is stored as a result of a machine check. This data will be used by an OCS processor to perform LRU isolation on other processors.

6.1.7.5.1.11 Processor Allocation - The processor allocation services of the master executive will effect a partitioning between the Experiment and Operational multiprocessors.

6.1.7.5.1.12 PSA Access - The Operational processors will be allowed to access a "diagnostic scan out" area within each PSA of other processors for failure detection/isolation purposes.

6.1.7.5.1.13 Memory Unit Configuration Control - All memory units contain a configuration control register and an address translation register to facilitate real-time changes in configuration.

6.1.7.5.1.14 Memory Addressing - Units are addressed relative to "zero" to permit logical substitution among memory units. An actual address is formed by a processor, utilizing the sum of the contents of the address translation register and the relative address within the memory. This process is transparent to software.

6.1.7.5.1.15 Duplicate Executive Capability - Duplicate copies of the master executive will be maintained in main memory to avoid loss of configuration control.

6.1.7.5.1.16 Data Bus Controller (DBC) I/O Operations - It is assumed that the data bus controller can execute I/O operations independent of processor operations by obtaining data bus program from main memory (similar to the channel operation in the IBM System/360). The assumption allows the processor to be devoted to main storage programs leaving the comparatively slow I/O programs to the bus controller.

6.1.7.5.1.17 DBC Configuration Control - The data bus controller contains a configuration control register to facilitate real-time changes in configuration.

6.1.7.5.1.18 Processor-to-Processor Data Flow - The DBC provides a processor-to-processor data flow path for improved configuration flexibility.

6.1.7.5.1.19 Data Bus Command Word Format - A sample format for the data bus controller command word is shown below.

COMMAND	DATA ADDRESS (IN SHARED MEMORY	FLAGS	000		BYTE COUNT
0 7	8 31	32 36	37 39	40	48 63

6.1.7.5.1.20 Data Acquisition I/O Operation - An I/O operation will be initiated by a processor instruction (e.g., Start I/O) containing an operand which addresses down to the data bus terminal level in the data path. The format is shown as follows:

16 BITS

DBC	SPARE	TERMINAL	SPARE
2 BITS	4 BITS	7 BITS	3 BITS

The data bus controller will be commanded by the processor I/O instruction to fetch a data bus command program from main storage. The program will supply the additional addressing and commands to be utilized by the lowest level in the data path (e.g., RDAU or SGU input/output).

6.1.7.5.1.21 Data Acquisition Command Structure - Typical RDAU commands will include:

- SEEK (address RDAU/line)
- WRITE RDAU MEMORY (set RDAU limits and mask)
- READ RDAU (sequential read of one or more RDAU channels. Channels addresses "wraparound" from highest to lowest)
- READ RDAU MEMORY (read RDAU limits and mask)

16 BITS

SEEK	SPARE	RDAU	LINE

The SGU will be handled as in the case of an RDAU; i.e., a "start I/O" instruction and channel program. The format is as follows:

16 BITS

STIMULATE	SPARE	SGU NUMBER	WAVEFORM

Discrete command outputs to any subsystem will be handled through the data bus terminal. The format is as shown:

16 BITS

STIMULATE	SPARE	DATA BUS TERMINAL NUMBER	ADDRESS LINE

6.1.7.5.1.22 Controls and Displays - The controls and displays will be treated similarly to the RDAU; i.e., they will respond to a specific set of instructions contained in a data bus command program. The Experiment and Command/Control consoles will be handled the same.

6.1.7.5.1.23 Polling Technique - The fundamental method of announcing out-of-tolerance conditions (which must generate an unexpected interrupt) is via a hardware polling. Each RDAU, independently of command, limit checks all inputs. Out-of-tolerance conditions will be stored in a register within the RDAU. Each terminal must poll the RDAU continuously and store any out-of-tolerance conditions. The data bus controller will poll the terminals for interrupt conditions. All subsystems which interface with the terminals will announce special status conditions in the same manner, i.e., conditions are announced in the same bit positions. Unused RDAU channels will be masked to avoid generating interrupts. The mask of the secondary RDAU will prevent two separate interrupts from occurring because a single test point signal is out of limits.

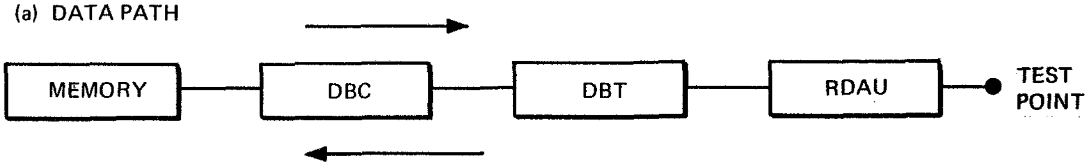
6.1.7.5.1.24 Functional Levels of Operation - Throughout test descriptions where "reconfiguration" or "configurable element" is used, the subdivisions are as defined in the following hierarchy.

- SUBSYSTEM
- CONFIGURATION
- CONFIGURABLE ELEMENT
- LINE REPLACEABLE UNIT (LRU)

The "Subsystem" level includes the complete DMS equipment. A "Configuration" represents a particular combination of DMS equipment utilized at a given time (e.g., the particular bus controller, bus terminal, and RDAU in use at a given time). A "Configurable Element" is the level at which DMS reconfiguration is performed. A "Configurable Element" can be comprised of one or more LRUs (e.g., the processor contains multiple LRUs). The LRU is the smallest denomination of equipment for which fault isolation is attempted and is the level at which "on-line" remove-and-replace maintenance is performed.

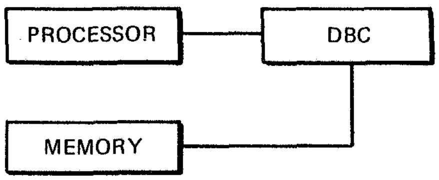
Participation of configurable elements in various DMS operations is shown below:

(a) DATA PATH

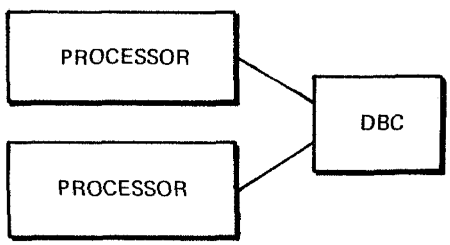


(b) STORED-PROGRAM EXECUTION

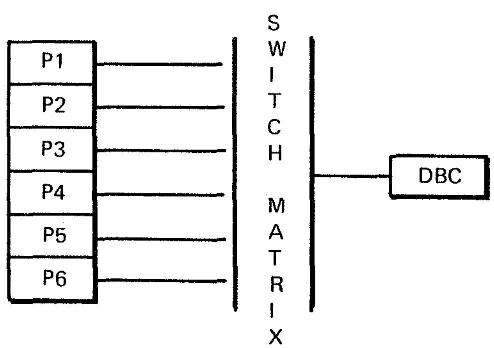
(c) I/O OPERATIONS



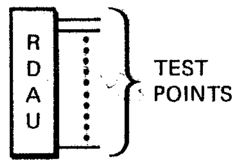
(d) SHOULDER TAP



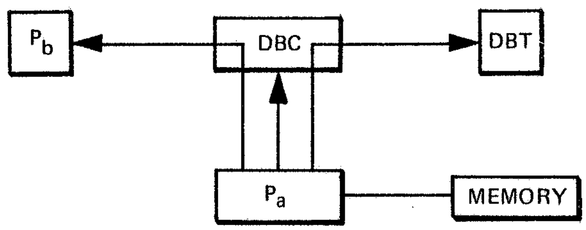
(e) UNEXPECTED INTERRUPT PRESENTATION



(f) TEST POINT POLLING



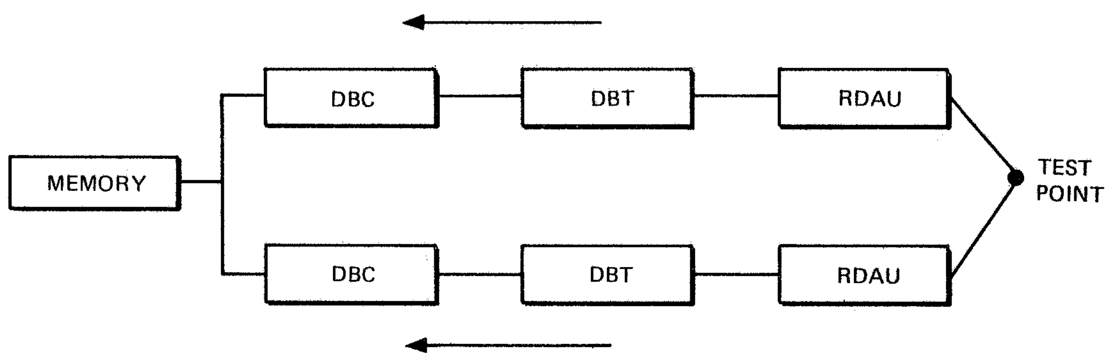
(g) SET CONFIGURATION CONTROL REGISTERS



P_a - OPERATIONS PROCESSOR

P_b - EITHER AN EXPERIMENT OR AN OPERATIONS PROCESSOR

(h) PRIMARY/SECONDARY DATA PATH



NOTE:
A FAILURE AT ANY POINT IN THE DATA PATH FROM THE DBC TO THE RDAU CAN CAUSE A RECONFIGURATION TO THE SECONDARY DATA PATH

6.1.7.5.2 COM Test Software Sizing

The general organization and descriptions of Continuous Orbital Monitoring tests are shown pictorially in Figure 6-23. Three main groupings occur based on the rate at which each group is performed. Within each group, there is included the item being tested and the name of a test implemented on the item under test. There is another category not shown in Figure 6-23, i.e., an "ON DEMAND" group initiated by the crew. Accompanying each test is an estimate of CPU time, memory required, and the I/O time if applicable. The CPU times are based on a 1 microsecond memory cycle time and instruction timing formulas of the System/4 Pi Model EP computer. Where System/4 Pi timing formulas were used, the times were scaled to take into account the 1 microsecond memory (4 Pi EP memory cycle time is normally 2.5 miscroseconds). Where System/4 Pi EP instructions were not available for the study, appropriate System/360 timing formulas were used.

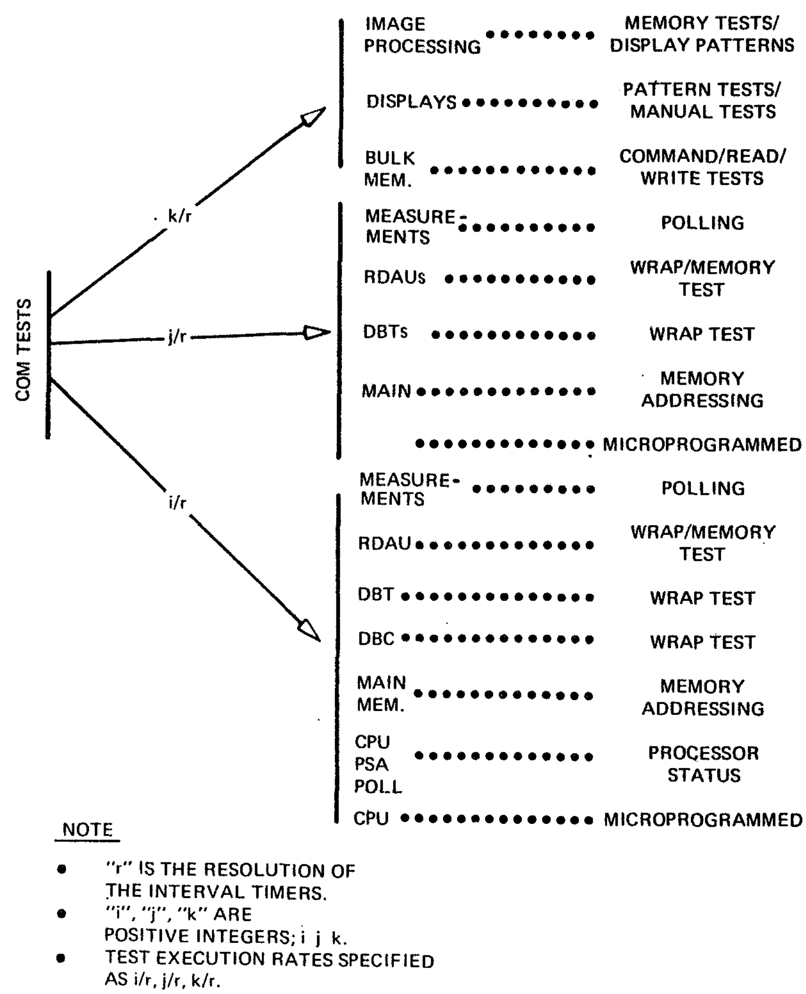


Figure 6-23. COM Test Organization

6.1.7.5.2.1 <u>CPU COM Test</u> – It is assumed that the CPU test is microprogrammed and initiated with a "DIAGNOSE" instruction. For timing purposes, it is assumed that the test requires 10 milliseconds to execute. The results of the test are read out to a "diagnostic scan out" area of the processor preferential storage in shared main memory. The test results are accessible by other processors for fault detection/isolation purposes. In the assumed implementation there are two methods of indicating that a CPU is in trouble:

- The processor-to-processor link via the bus controller. This would be a "write direct" to the OCS processor which would generate a machine check interrupt.

- If the above path fails, the OCS processor will poll PSAs to look at the diagnostic scan out area for all processors.

The flow and sizing estimate for the diagnostic scan out area poll are shown in Figure 6-24.

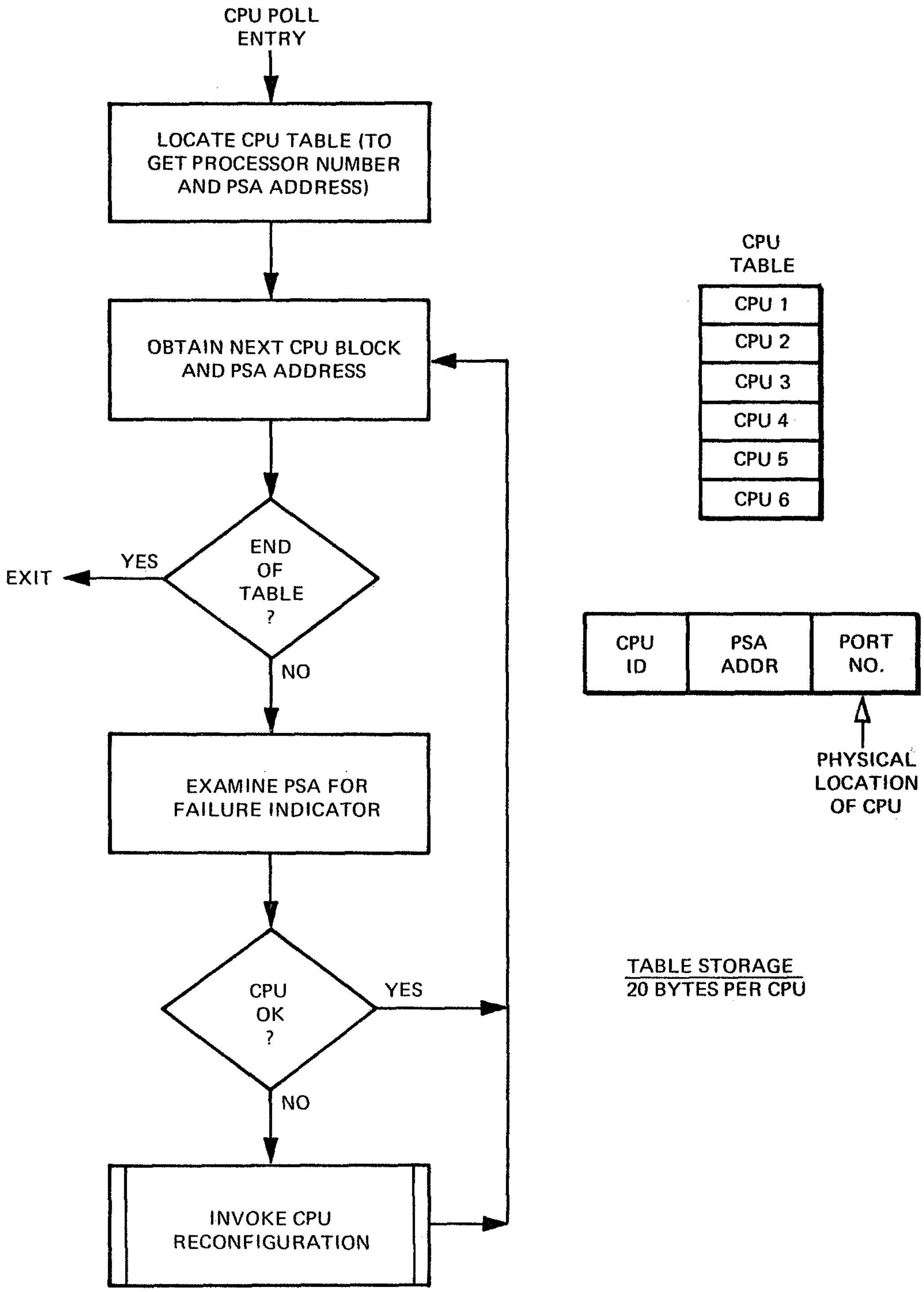
6.1.7.5.2.2 <u>COM Memory Addressing</u> – The memory addressing test will consist of addressing all main memory locations. A location which cannot be read will cause a parity error. The flow and sizing estimate are shown in Figure 6-25.

6.1.7.5.2.3 <u>Data Bus Controller COM "Wrap" Test</u> – This test consists of issuing special I/O commands to configure the DBC to a test mode. A hardware feature in the DBC will permit a pattern from main memory to be transferred to the DBC which will "wrap" the pattern to the lines to be relocated in memory. The patterns returned to memory are compared to those sent for failure information. The patterns will be stored on a byte basis and there will be 256 patterns or bytes. The "wrap" test will be performed on all four data bus controllers. The command word format will be as shown below.

SEND →	DBC WRAP WRITE	MAIN STORAGE ADDRESS FOR PATTERN TO CONTROLLER	CHAIN FLAG
RECEIVE →	DBC WRAP READ	MAIN STORAGE ADDRESS FOR RETURN PATTERN	

The test flow and sizing estimate are shown in Figure 6-26.

6.1.7.5.2.4 <u>Data Bus Terminal COM "Wrap" Test</u> – This test will be identical to the data bus controller "wrap" test where I/O commands will configure the DBT to a test mode. Patterns will be transferred from memory to the terminal



LOOP TIME = 60 USEC FOR 6 CPUs (10 USEC/CPU)
TOTAL TIME = 106 USEC ± 12
MEMORY = 30 ± 6 WORDS

Figure 6-24. CPU Diagnostic Scan Out Area Poll

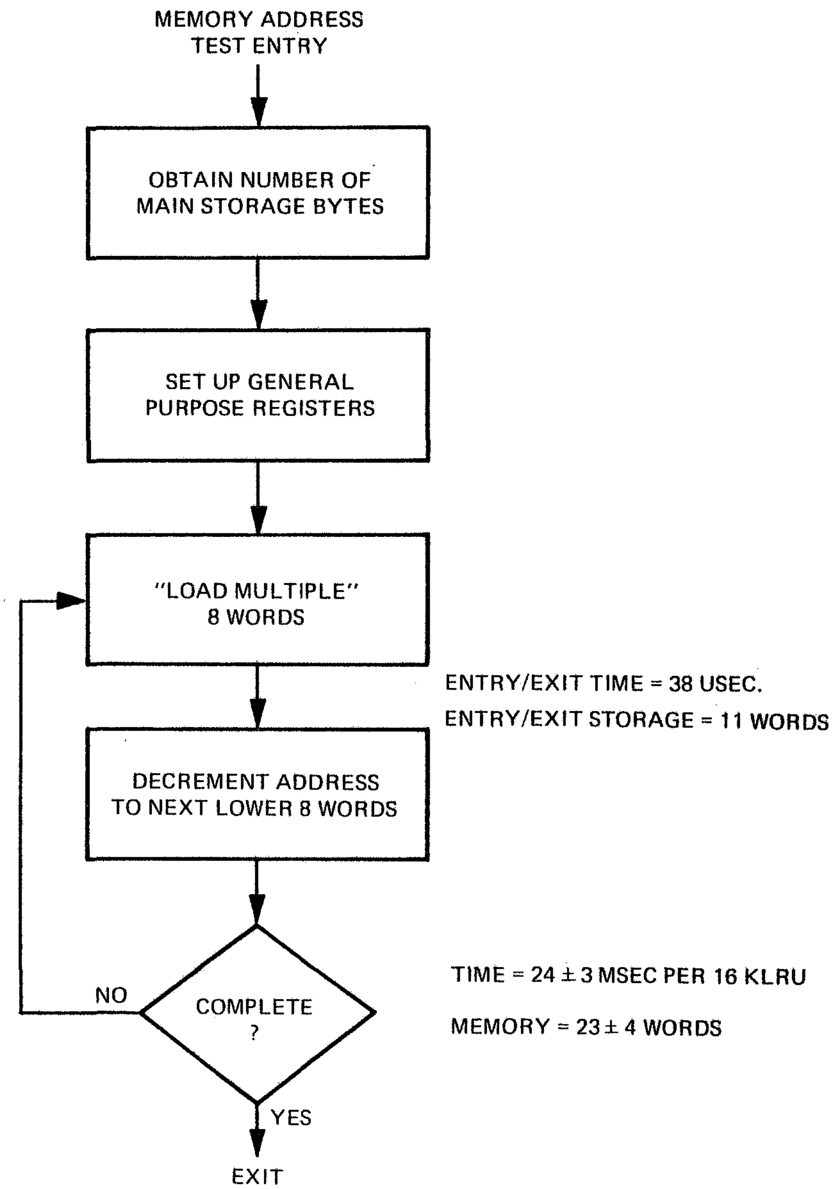


Figure 6-25. Memory Addressing Test Flow

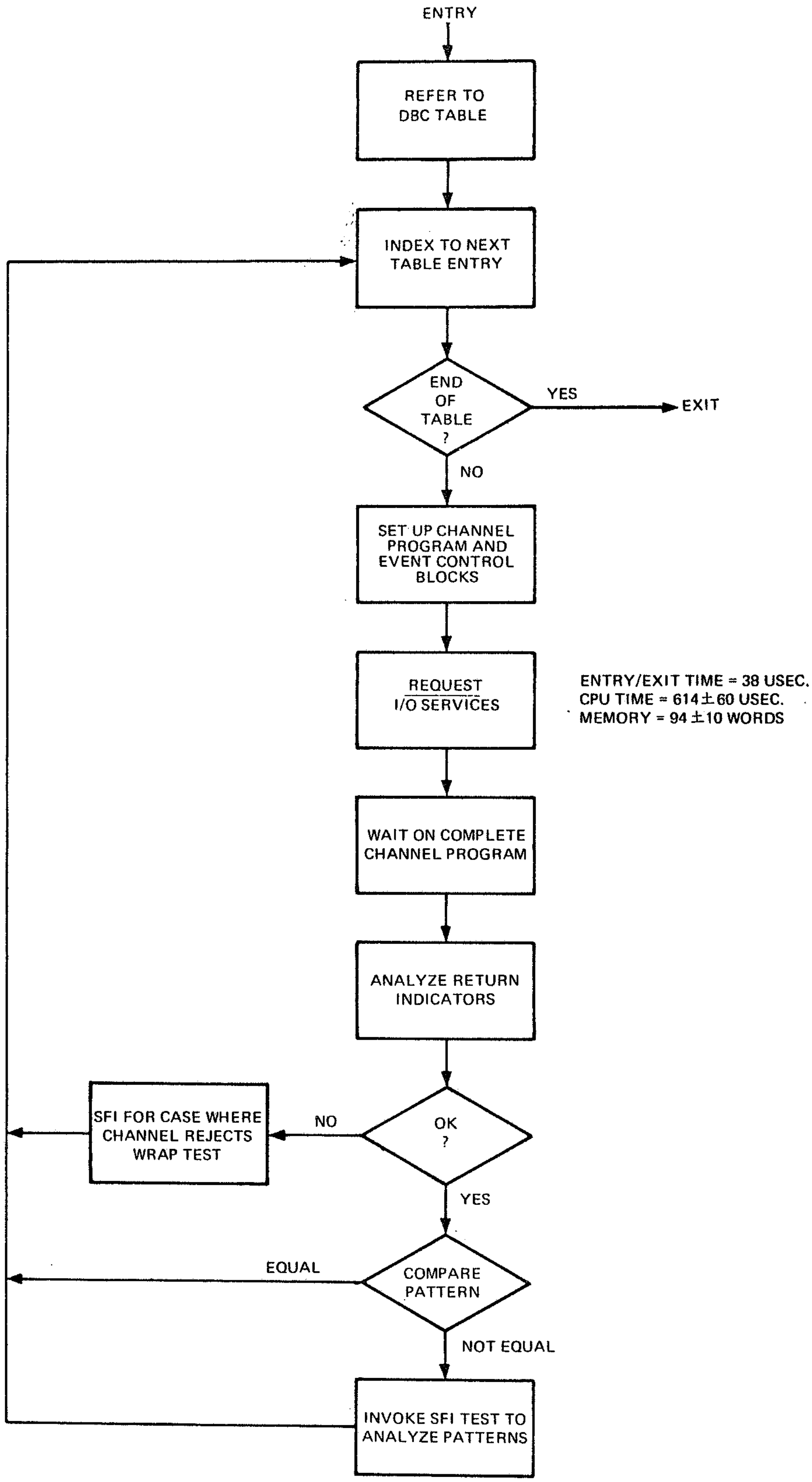


Figure 6-26. DBC COM Wrap Test Flow

and returned to memory for comparison. The patterns are stored on a byte basis, and there will be 256 patterns or bytes. The command word format is as shown below:

SEND →	DBT WRAP	MAIN STORAGE ADDRESS FOR PATTERN TO TERMINAL	
RECEIVE →	DBT WRAP	MAIN STORAGE ADDRESS FOR RETURN PATTERN	

There is an additional "time" or delay involved in this test; i.e., there is an I/O time required for the serial transfer of the patterns to the terminal and for the serial return. I/O time is based on a data bus bit rate of one megabit per second.

The flow is essentially the same as for the data bus controller "wrap" test (Figure 6-26). The sizing estimate is as follows:

ENTRY/EXIT TIME = 38 usec

CPU Time/Terminal = 397 ±40 usec

Memory = 98 ±10 words

I/O Time/Terminal = 4096 usec

NOTES: 1. Data bus time is the transfer of 256 bytes at 16 usec per byte. Total I/O time = 200,000 usec for 50 terminals.

2. The CPU time is 46 + 351 n, where "n" is the number of terminals. Total CPU time is 17,600 usec for 50 terminals.

6.1.7.5.2.5 RDAU COM Tests - There are two tests associated with the RDAUs; i.e., one is similar to the DBC/DBT wrap tests, and the second is a memory/multiplexer test. In the first test, a form of "wrap" test is performed but a pattern is not transferred from main memory. Instead, a DC voltage developed within the RDAU is connected to one channel of the multiplexer. The voltage is converted to digital and transmitted to the CPU for comparison to an expected value. The flow is essentially the same as for the DBC/DBT tests (Figure 6-26) and, for this reason, is not repeated. The sizing estimate is as follows:

ENTRY/EXIT TIME = 38 usec

CPU TIME = 18,750 ±1875 usec (for 133 RDAUs*)

MEMORY = 38 ±4 words

I/O Time = 1400 ± 1400 usec (105 usec/RDAU)

*Formula for CPU time = 46 + 138 n, where n = number of RDAUs.

The second RDAU test is the memory/multiplexer test. In this test the contents of RDAU memory are read to verify that the contents are as expected, and then a sequential "read" is made to verify all channels of the multiplexer. The approximate RDAU memory assumed is:

LIMITS	64 Bytes
ANALOG MASK	4 Bytes
DISCRETE MASK	4 Bytes
EXPECTED DISCRETE PATTERN	4 Bytes
TOTAL	76 Bytes

The total entry/exit time, CPU time, and I/O time for the tests will be the sum of the times required for the individual tests. The test flow for the memory/ multiplexer test and the sizing estimate are shown in Figure 6-27.

6.1.7.5.2.6 Image Processing COM Tests - An assumption is made that a crew member must manually initiate or commit a device within image processing to actual test performance.

The COM tests cannot interrupt any operation being executed within the experiment group or within bulk memory. It is assumed that a recommended schedule for testing will be relayed to the crew via a CRT display.

In the actual image processing test, the only OCS processor participation is in the check of the permanent and working digital storage and displays (again it is performed only upon authorization or request by a crew member because the test may destroy memory contents). The actual memory tests will consist of transmitting patterns from the OCS to the memories and rereading the memory for pattern comparison. After completion of the memory test, a display pattern is written on the CRTs. The display test pattern will contain all alphanumerics which will be observed by the crew. Successful completion will be entered into a keyboard. The remainder of the image processing group is assumed manually controlled through BITE equipment. These tests will not affect the software sizing. The test flow for the memory test is shown in Figure 6-28.

For the display part of the image processing tests, additional display assumptions were required. These include:

- Operation similar to IBM 2250 Display
- Vector capability
- At least 64 characters

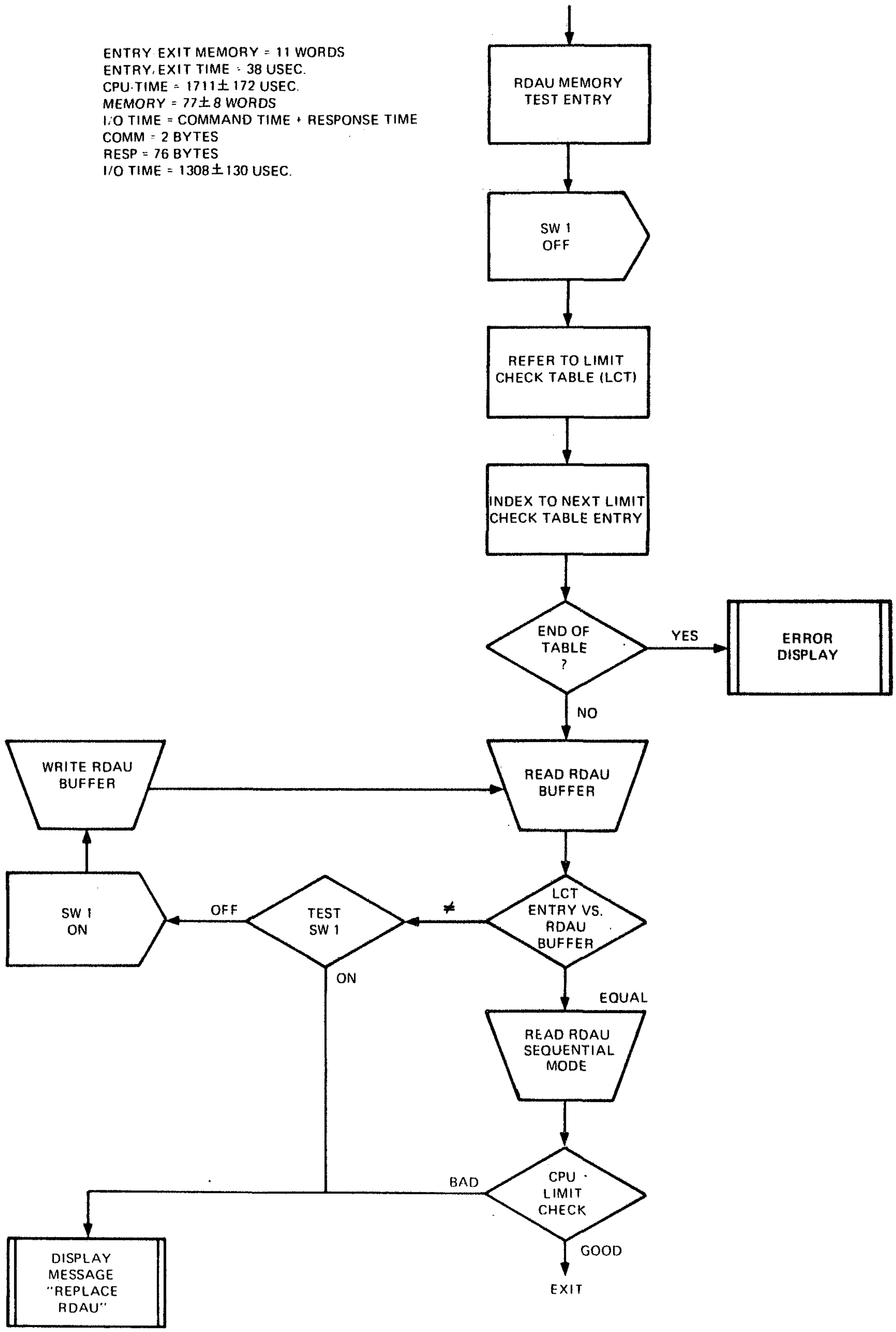


Figure 6-27. RDAU Memory/Multiplexer Test Flow

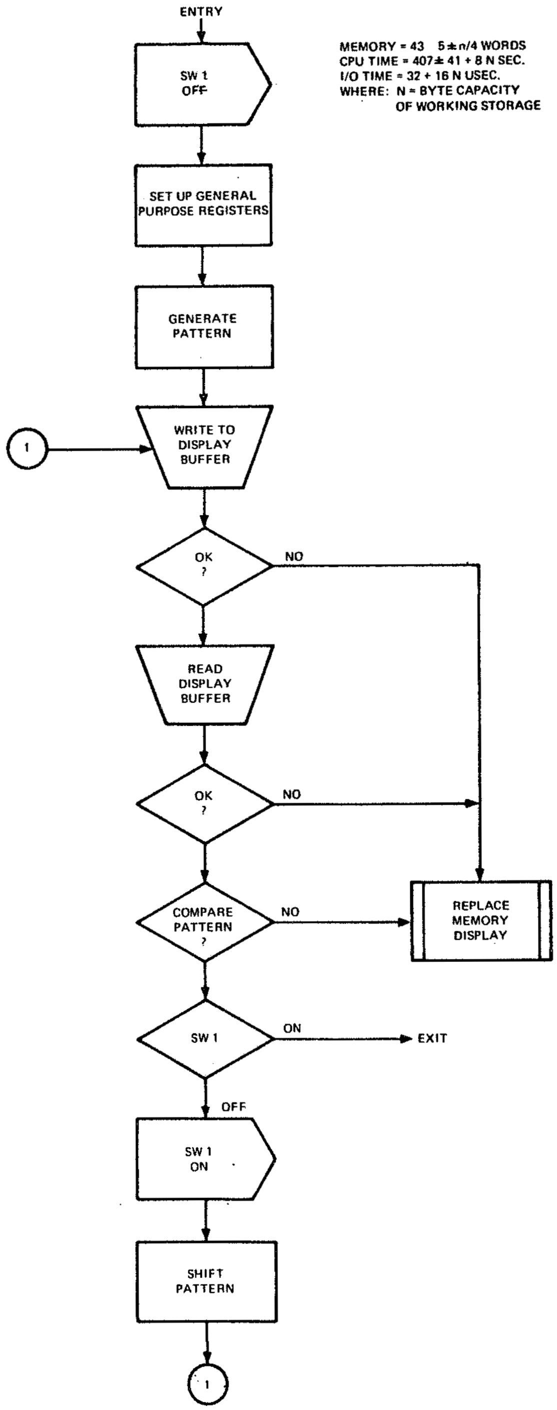


Figure 6-28. Image Processing COM Memory Test Flow

A candidate display pattern which can be sized is shown in Figure 6-29. The display utilizes all symbols, numerics, vectors, etc. The flow for the test pattern is shown in Figure 6-30.

6.1.7.5.2.7 Bulk Memory COM Tests - The bulk memory tests will be authorized by a crew member as in the image processing tests. In the case of tapes, a crew member must mount a special test tape. The actual tests for peripheral devices are fairly standard and consist of the execution of the various device commands and of writing/reading bit patterns. A top level flow for the bulk memory tests is included in Figure 6-31. Sizing estimates are based on the IBM System/360 On Line Test System (OLTS).

6.1.7.5.2.8 DMS COM Measurement Limit Checks - In addition to the software programs and BITE provisions, a series of measurements must be made on certain DMS equipment. The measurements will be concerned principally with power supply measurements and temperature measurements.

Since each RDAU independently polls and limit checks measurements, there is no separate program flow as such. If an out-of-tolerance condition occurs, it ultimately causes a program interrupt and the RDAU is checked through a "wrap" and "memory/multiplexer" tests discussed earlier.

6.1.7.5.2.9 GN&C Preprocessor COM Test - Without explicit details of the preprocessor characteristics, actual test descriptions cannot be evolved. For purposes of sizing the DMS-OCS, it is assumed that the preprocessors have an integral test capability through incorporation of BITE, and that they will respond to test commands from the OCS via the data bus. The response from the

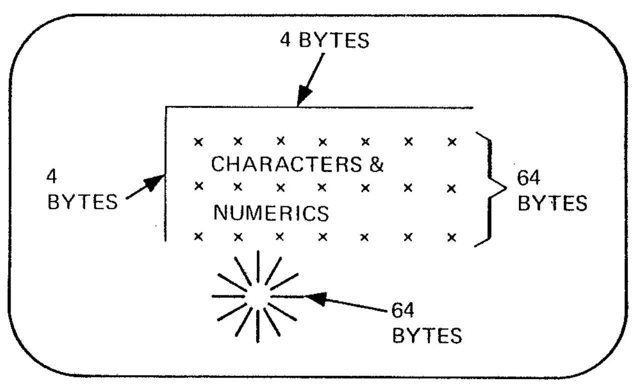


Figure 6-29. Sample Display Test Pattern

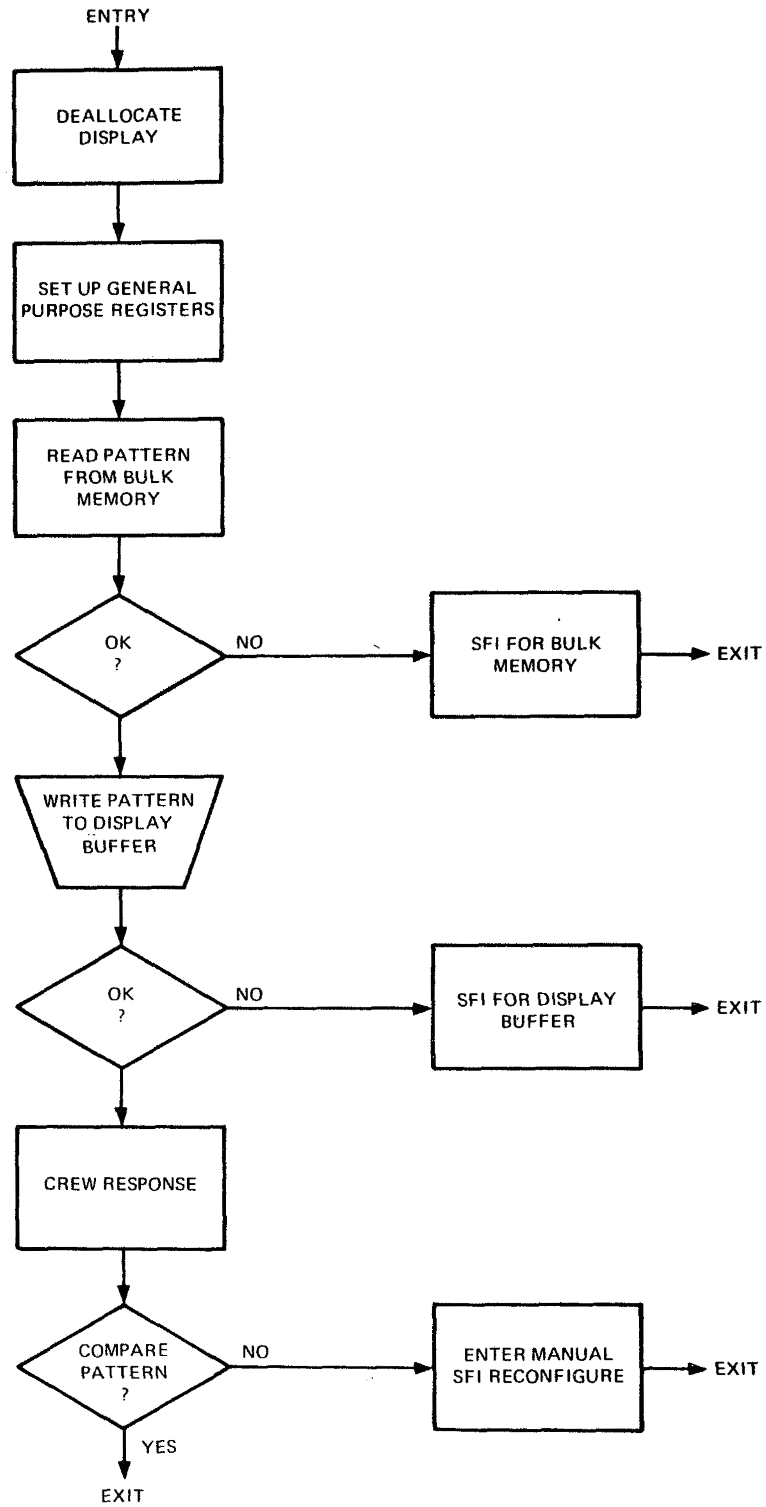


Figure 6-30. Image Processing Display Test Flow

preprocessors is assumed in the form of a GO/NO GO discrete signal. The power supplies for each preprocessor will be monitored and limit checked by RDAUs. The sizing estimate is as follows:

Memory = 100 ±50 words

CPU Time = 40 ±20 usec

I/O Time = 100 ±30 usec/processor

6.1.7.5.3 Subsystem Fault Isolation Test Software Sizing

In many cases, the performance of the COM tests, through the device addressing, inherently yields fault isolation. Consequently, many of the SFI tests will be common to the COM tests. The capability must exist for performing any of the COM tests (which may be utilized as SFI tests) upon initiation by a crew member. The SFI tests which are common to the COM tests include the CPU tests, data bus controller, data bus terminal, RDAU, displays, bulk memory, and image processing. Unique tests are required in the area of memory units and switch matrices.

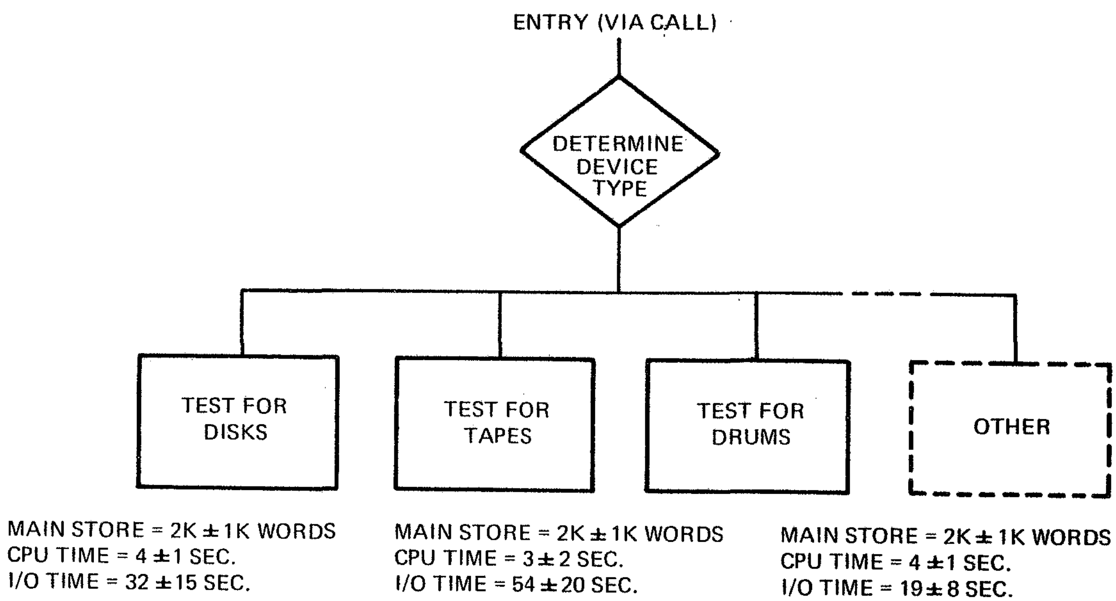


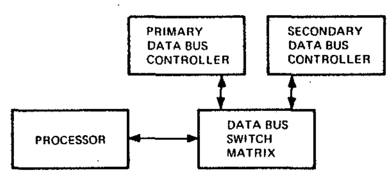
Figure 6-31. Bulk Storage COM Tests

6.1.7.5.3.1 Shared Main Memory - The COM main memory test checked to determine if each memory location could be addressed. The SFI test consists of generating a pattern in one location in memory, writing the pattern into the memory under test, and re-reading the pattern to compare it to the original pattern. The SFI flow and sizing estimate for the memory test is shown in Figure 6-32.

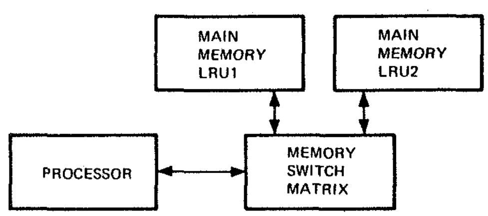
6.1.7.5.3.2 Switch Matrix - There are two switch matrix units in the baseline; i.e., a data bus controller switch matrix and a memory switch matrix. There will not be an explicit switch matrix test, but rather one of the COM tests may be attempted in different configurations to logically isolate the problem.

Three cases have been considered for problems associated with the switch matrices.

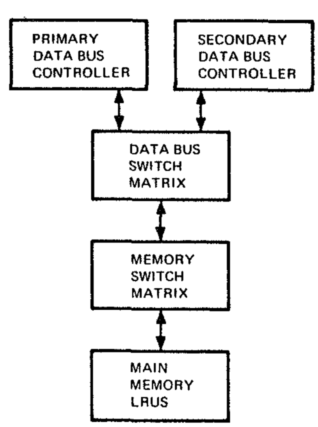
- Case "A" - A problem exists in communication between a processor and a data bus controller as shown below:



- Case "B" - A problem exists in communication between the processor and memory as shown below:



- Case "C" - A communication problem exists between the data bus controllers and main memory as shown below:



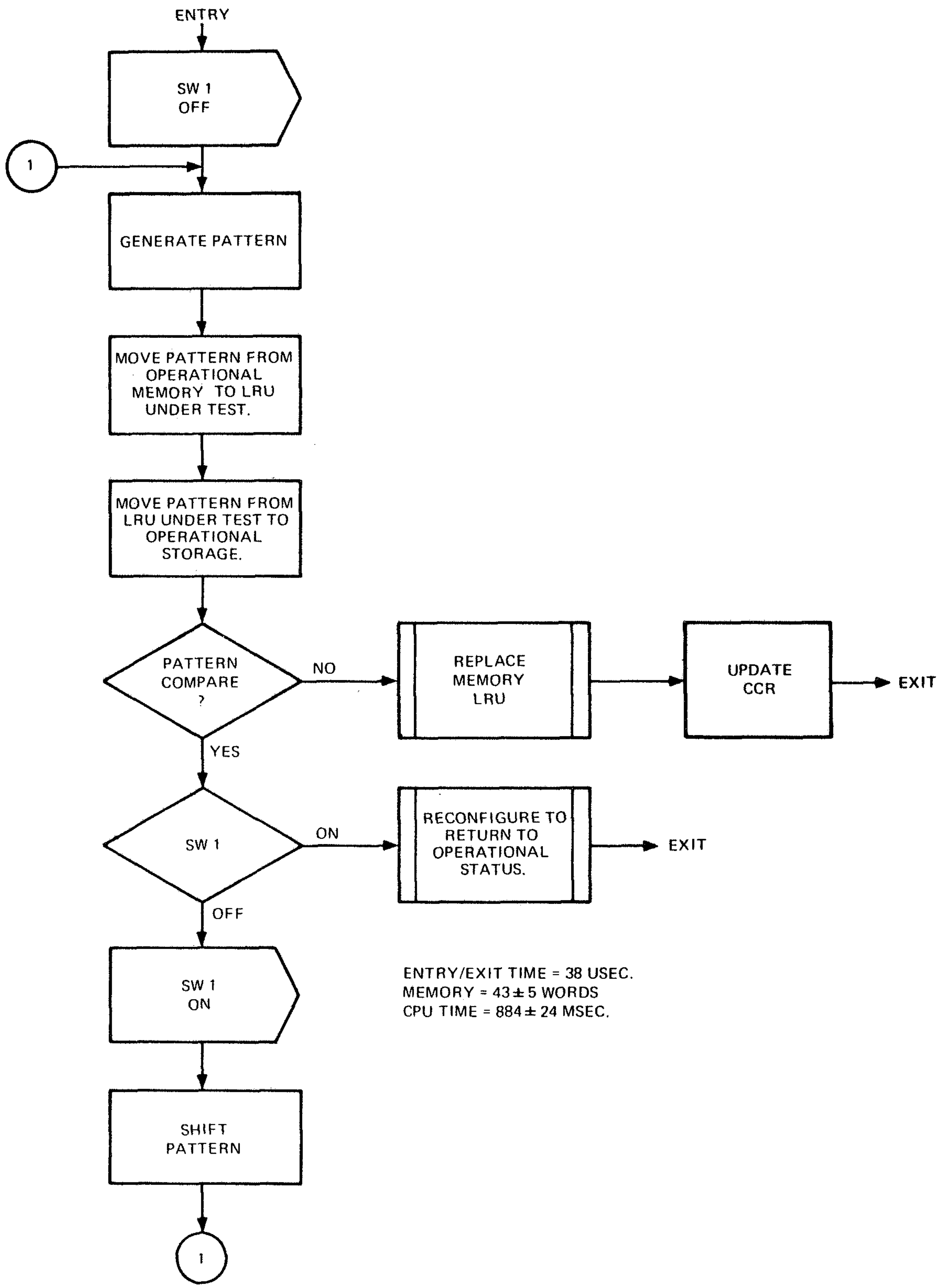


Figure 6-32. Shared Main Memory SFI Flow

Flows for Cases "A," "B," and "C" are shown in Figures 6-33, 6-34, and 6-35.

The aggregate of CPU time and memory required to implement the three cases described is:

CPU time = 200 $\pm$160 usec

Memory = 150 $\pm$100 words

6.1.7.5.4 DMS Reconfiguration Software Sizing

A set of subsystem elements in which communication and control paths are established constitutes a prevailing "configuration." When elements are added, deleted, or substituted, a new configuration is created; the process of establishing the new configuration is called "reconfiguration." Whenever reconfiguration takes place, the total resources of the subsystem have changed, and appropriate actions are required such that OCS is aware of the conditions. Reconfiguration can be invoked due to failures or due to a resource reallocation, but this report does not consider the latter. Configuration control normally is under program control, i.e., reconfiguration will occur automatically via OCS. Display messages will be sent to the crew for notification of reconfiguration or for cases where manual actions are necessary.

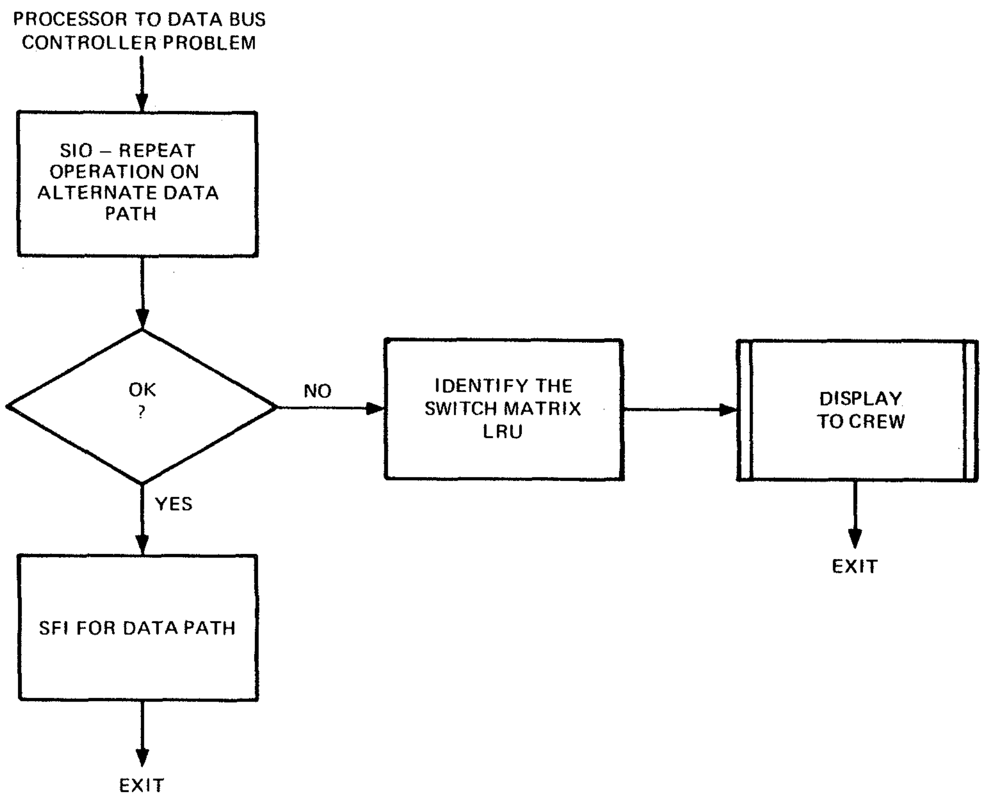


Figure 6-33. Case "A" Flow

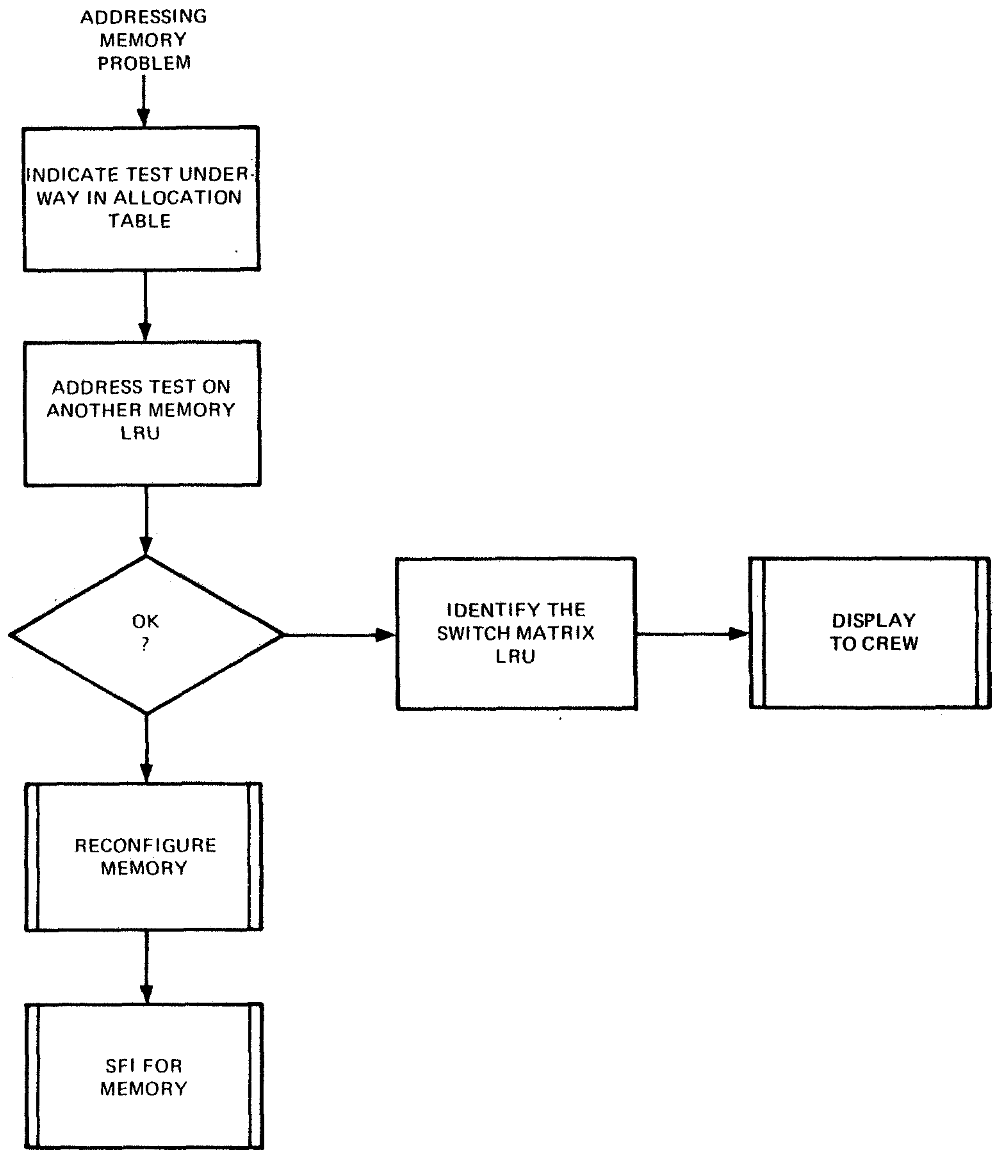


Figure 6-34. Case "B" Flow

Depending on the source of error or malfunction, certain events must occur. In the event of a memory element failure, it must be determined what the contents were, if the contents are recoverable, or if the data is available from other sources, and what program restart steps are necessary. In the case of an I/O failure, configuration control registers and the bus controller table must be updated. If a CPU fails, other CPUs must be notified, and some form of analysis of the intermediate results from that processor may be required. For bulk memory failures, it is necessary to update the bulk memory allocation table. Figures 6-36 through 6-39 show representative flows for the CPU, main memory, the data acquisition path, and bulk memory. CPU time and memory estimated for each are included in the figures.

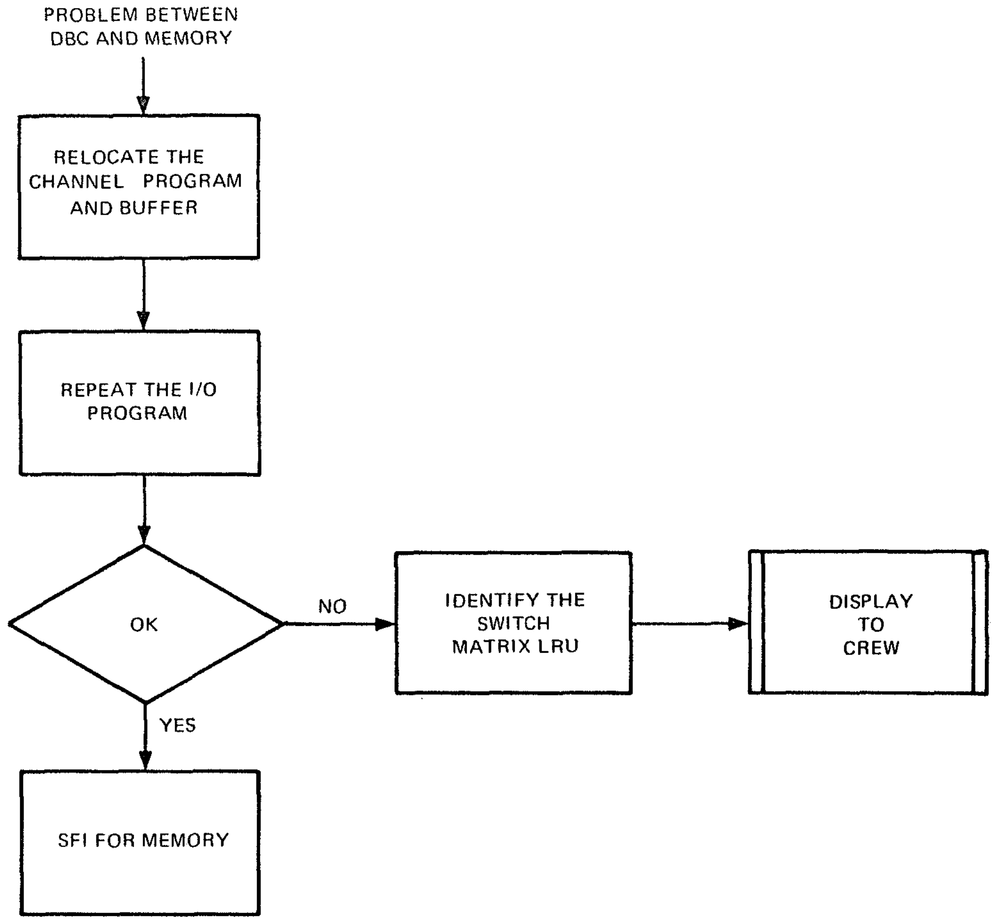


Figure 6-35. Case "C" Flow

6.1.7.5.5 Program Restart Software Sizing

Subsequent to the steps of detection, isolation, and reconfiguration, it is necessary to resume program operation - ideally with nothing lost in the form of data. Attempting program restart without loss of data necessitates even further definition of the types of data inputs and of the baseline design.

The approach taken has been to define restart categories, assume one category (a worst case) for implementation, assume a technique for restart, define the system, generate the flows, and perform the sizing estimate. The principal reason for assuming one design was that there were seven recovery categories with six failure modes or 42 possible analyses that could be performed. The case assumed was that a real-time data source was being used, that a failure had occurred in working storage, and that a checkpoint/restart technique would be utilized for recovery purposes.

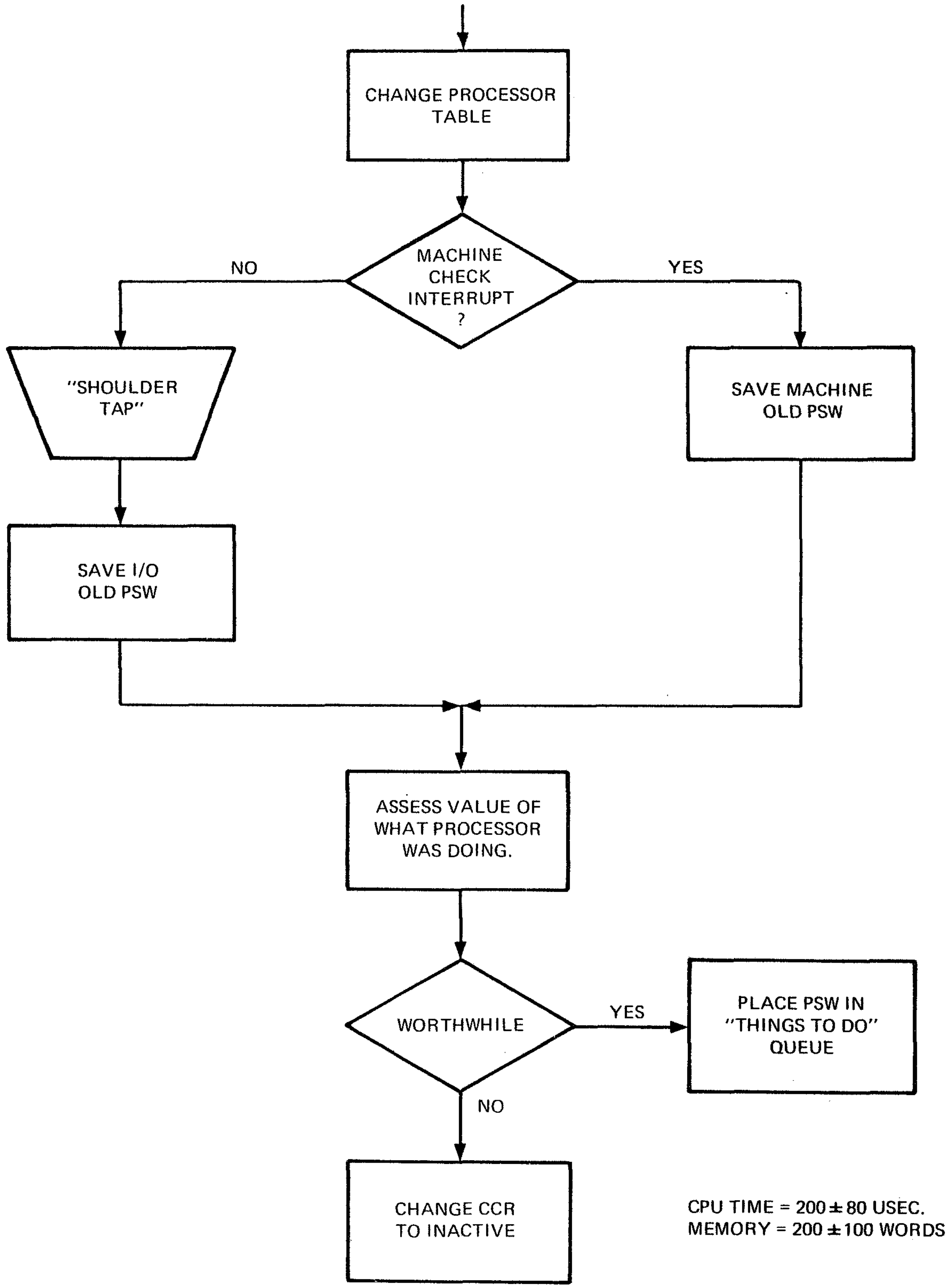


Figure 6-36. CPU Reconfiguration

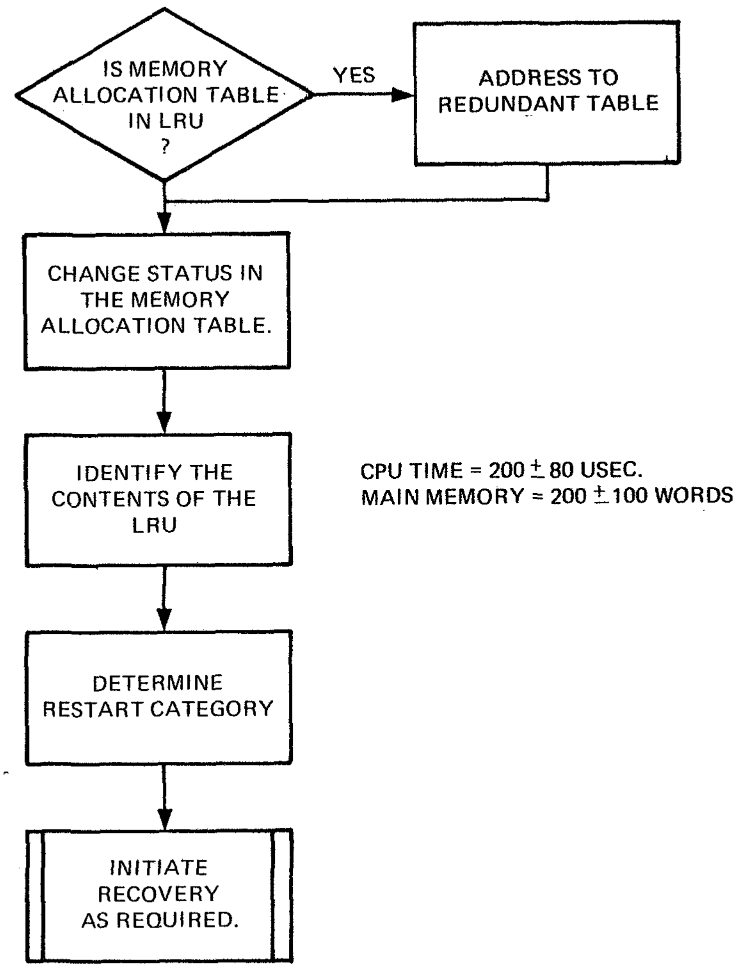


Figure 6-37. Main Memory Reconfiguration

6.1.7.5.5.1 Program Restart Categories - The various program restart categories arise due to variations in the character of data inputs, whether or not intermediate results are useful and should be utilized in recovery, or whether it is permissible to neglect past data and begin again. Seven restart categories are discussed below.

- In this category, the program is driven by real-time data and inter-arrival time between records, either explicitly or implicitly, forms part of the input. Recovery must make use of the results obtained when the program last ran, the data which caused the latest execution, and the time which has elapsed since the previous cycle.

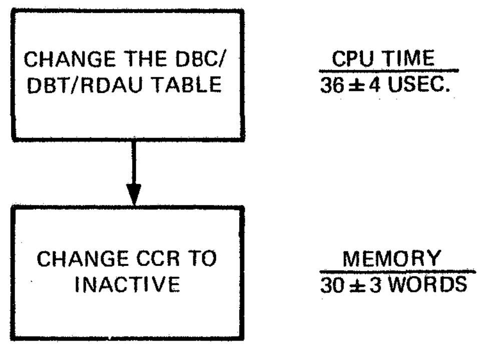


Figure 6-38. Data Acquisition Reconfiguration

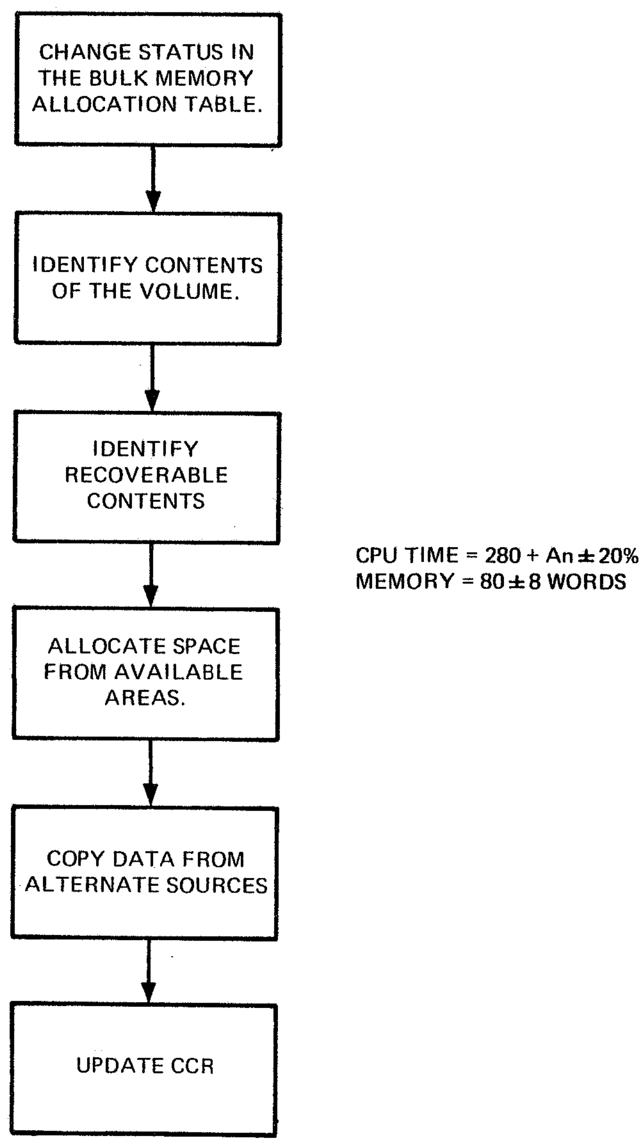


Figure 6-39. Bulk Memory Reconfiguration

- The same as in the previous paragraph except that the inter-arrival time is not a part of the program input.

- The program is driven by real-time data, but the results from previous executions can be ignored for the purposes of restart. Two subsets of this category would be where inter-arrival time is and is not significant as part of the input.

- The program does not process real-time data, but it is advantageous to be able to resume execution at some point other than the beginning of the input stream because of the time required for program execution. In this case, the intermediate results and the relative position in the input stream are checkpointed.

- Program does not process real-time data. Restart consists of re-positioning to the beginning of the input stream and rerunning the program.

- The program processes real-time data, but it is not necessary to log the data or to checkpoint the intermediate results. Restart consists of first refreshing the program text and then beginning execution with the first input event which occurs afterward.

- This is a degenerate category for programs which are terminated upon failure of any resource being utilized. Restart is accomplished manually.

NOTES:

1. Whenever real-time data is being processed, it is assumed that either the data rate or the program execution time is such that "catch up" after recovery is possible.

2. It is also assumed that the program is "refreshable"; i.e., program instructions are kept separate from data and inter-mediate results. It also is assumed that the program instructions are never altered.

6.1.7.5.5.2 <u>Restart Operation</u> - For analysis purposes the worst case restart category was assumed where real-time data was being processed, past results were required, and inter-arrival time of data is significant. Figure 6-40 shows a diagram indicating overall operation.

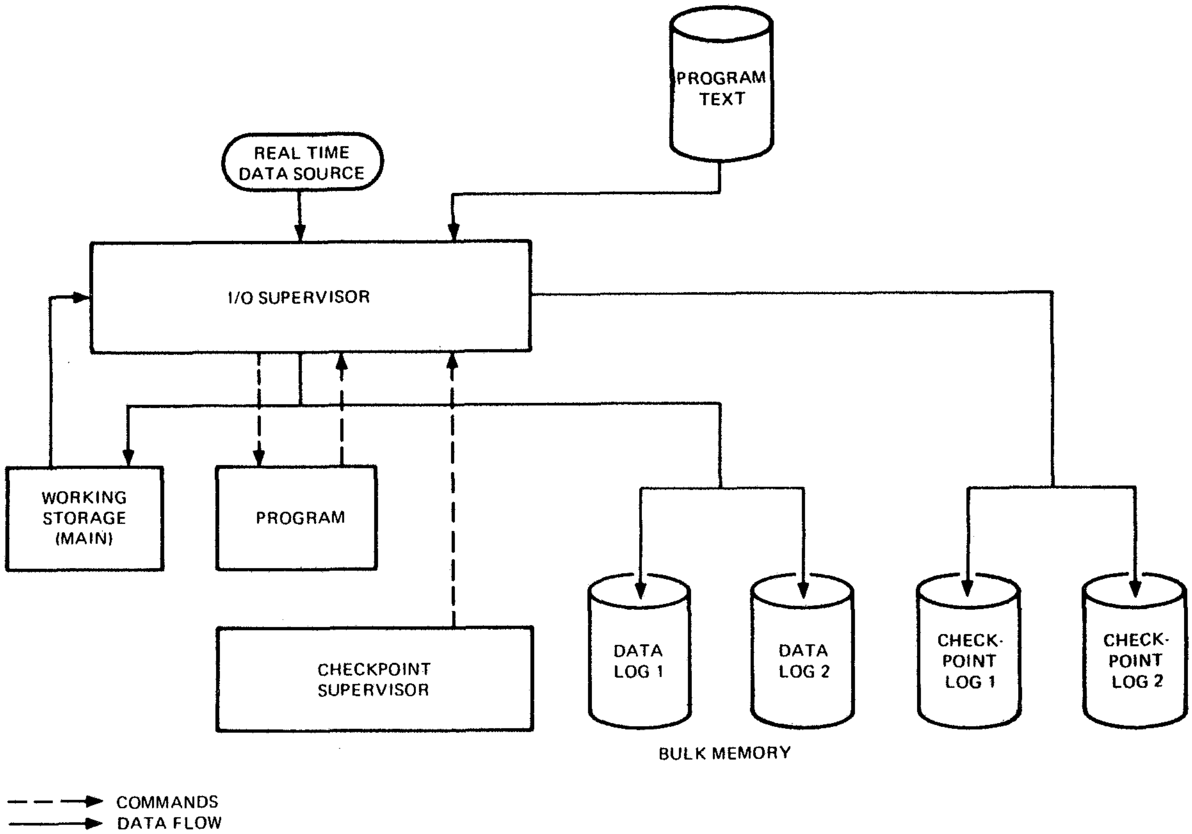


Figure 6-40. Diagram - Program Checkpoint and Data Logging Operation

In Figure 6-40, input data is via the Real-Time Data Source. The actual program executing is redundantly stored in bulk memory. The input data is fed to two places; i.e., to main working storage and to a data log (also in bulk memory). This is a temporary storage area for data between checkpoints (data log also occurs redundantly for recovery purposes). A checkpoint supervisor will cause intermediate results in working storage to be transferred to the redundant checkpoint log, under program control. If a failure occurs in the main program, reconfiguration will occur, the program text will be read into the new memory unit, intermediate results from the last checkpoint are read into working storage, and data from the last checkpoint will be utilized from the data log until the processor "catches up."

The sequence described represents that for a failure in a main storage unit containing an application program. For other failures there will be a somewhat different sequence. The failures which should be considered include:

(a) Main store unit containing program

(b) Main store unit containing working storage

(c) Processor failure

(d) Storage device containing data log

(e) Storage device containing checkpoint log

(f) Storage device containing program text

The actual sizing analysis has considered (a) only, but it is assumed that the other five failure modes will be approximately equivalent to (a) in complexity. Figure 6-41 shows a flow and sizing estimate for the sequence described previously.

Another aspect of program restart is the maintenance of continuity of operational data. This could be a failure external to the computer (e.g., within a bus controller, terminal, RDAU, or within bulk storage itself). Figures 6-42 and 6-43 are flows indicating how the data logs would be utilized during an unexpected interrupt emanating from an RDAU and from an attempt to read a record from a log which has failed.

6.1.7.5.6 Blocks and Tables

Maintaining configuration control, performing schedules, recovery, and failure verification, etc., imply several tables. There must be a table for device addresses down to the test point level, tables providing information on data paths, tables for scheduling the frequency of performing COM tests, failed item tables, memory allocation tables, a directory table to determine where the other tables are located, etc. The following is a preliminary list and sizing estimate for the blocks and tables assumed in this design. It also has been assumed that all tables must be redundantly stored.

6.1.7.5.6.1 <u>Device Address Table</u> - A table must be maintained for addresses down to the RDAU channel. The table should indicate (1 bit position) whether the primary or secondary data path should be used.

Memory = 4000 test points x 32 bits address = 8K words

Redundancy = 8K words

Total = 16K words

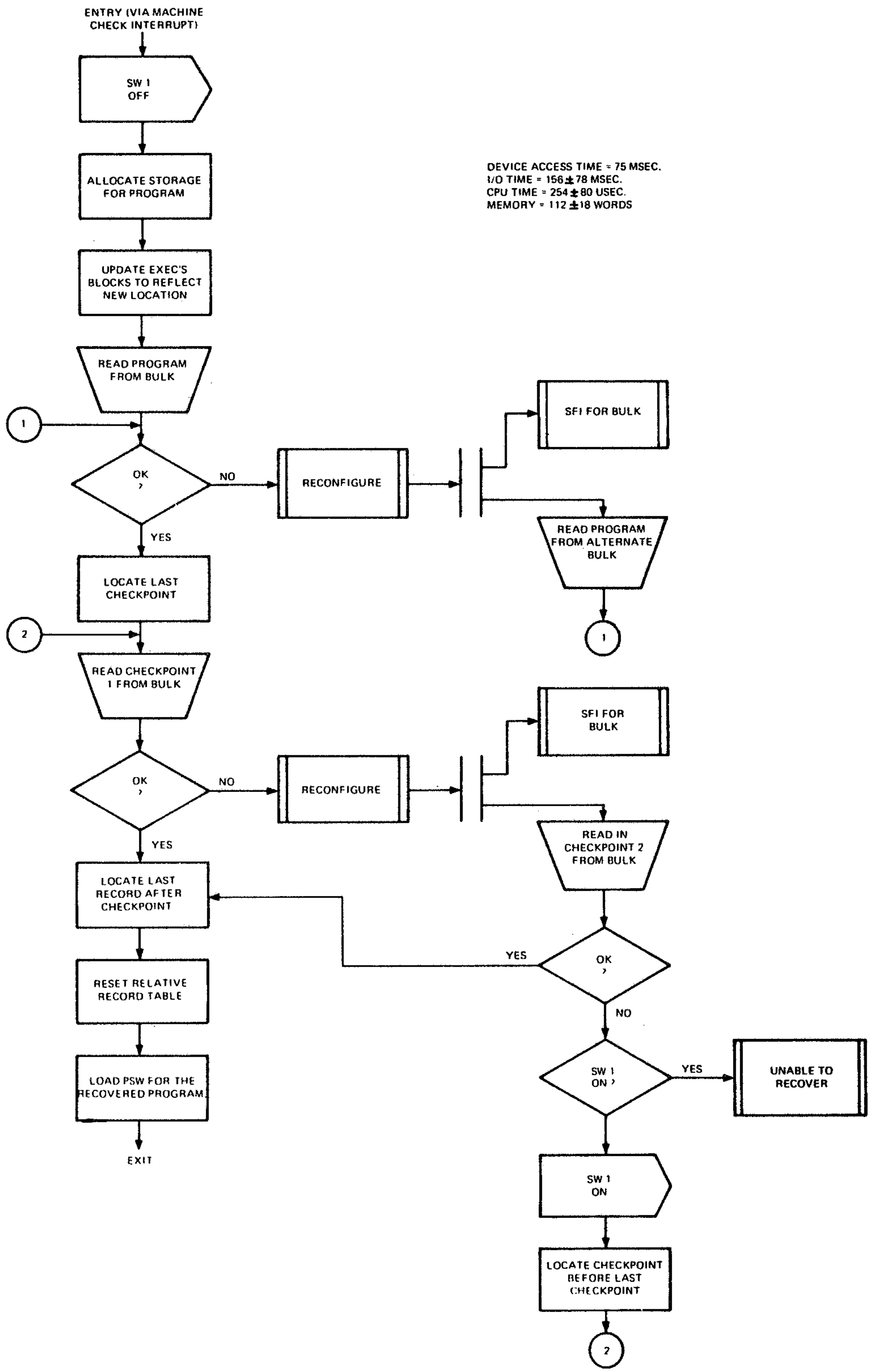


Figure 6-41. Program Restart Flow

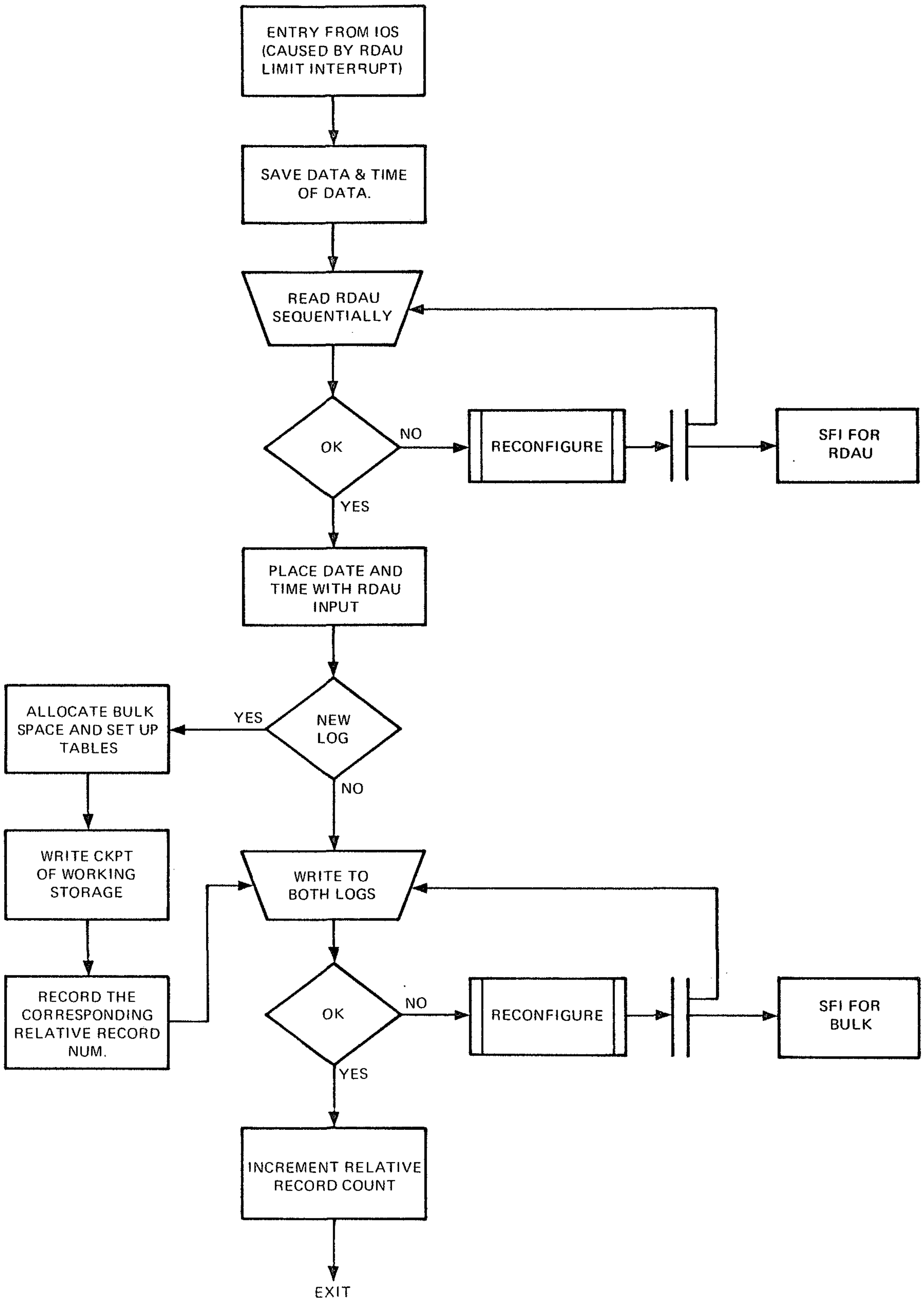


Figure 6-42. Log Supervisor 1

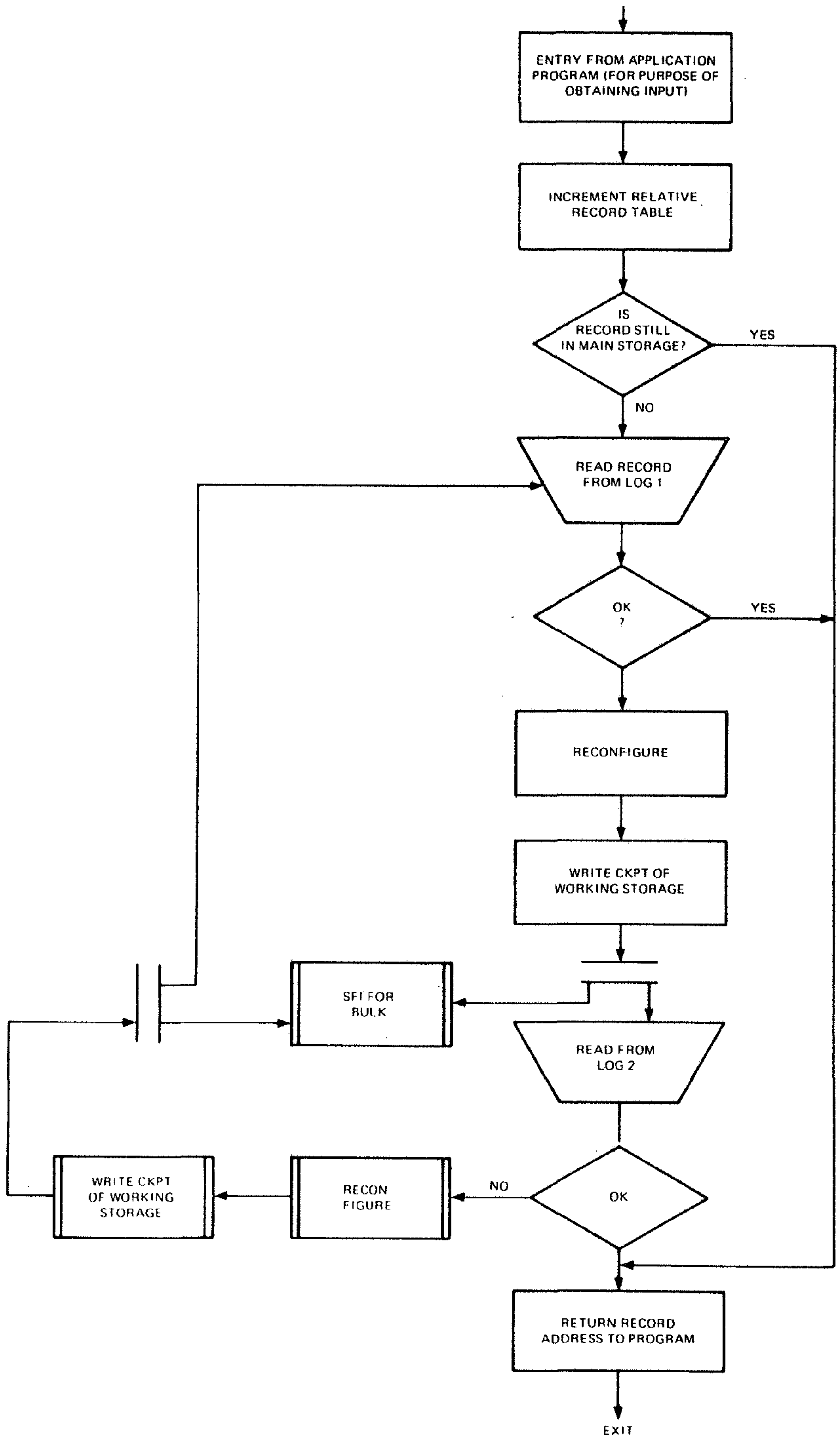


Figure 6-43. Log Supervisor 2

6.1.7.5.6.2 Data Path Table - This table indicates what bus controller, terminal, and RDAU are "on-line," what their addresses are, and whether they are operational, failed, under test, etc.

DATA PATH BLOCK

RELATIVE TEST POINT ADDRESS	PRIMARY POINTER TO DEVICE TABLE ENTRY	SECONDARY POINTER TO DEVICE TABLE ENTRY	3 WORDS

Memory = 4000 test points x 3 words/block = 12K words

Redundancy = 12K words

Total = 24K words

6.1.7.5.6.3 Limit Check Table - A copy of each RDAU memory must be maintained for each RDAU "read sequential." Verify the RDAU limit check mode.

RDAU Memory = 76 bytes (19 words)

Memory for 133 RDAUs = 133 x 19 = 2527 words

Redundant storage = 2527 words

Total memory = 5054 words

6.1.7.5.6.4 Processor Table - This table identifies each processor. It indicates the address of each processor's preferential storage area and the processor's operational status.

Memory = 6 processors x 4 words/proc. = 24 words

Redundancy = 24 words

Total = 48 words

6.1.7.5.6.5 Switch Matrix LRU Table - This table translates point-to-point switch matrix failures into LRU identification.

Total memory = 600 words (estimate)

6.1.7.5.6.6 Memory Allocation Table - This table indicates what main storage LRUs are free, operational, under test, etc.

Memory = 22 LRUs x 4 words/block = 88 words

Redundancy = 88 words

Total = 176 words

6.1.7.5.6.7 Rate Table - This table is used to initiate events such as the COM tests which may occur at specified frequencies; e.g., once per 20 seconds, once per hour, etc. A priority also must be stored with each event. For sizing purposes, it is assumed that there may be 250 COM test events and 50 OCS executive events and that each event has a 2 word block size.

EVENT IDENTIFICATION	Δt RATE	TIME OF LAST INITIATION, t_i	2 WORDS
32 BITS	16 BITS	16 BITS	

Memory = 300 events x 2 words/block = 600 words

Redundancy = 600 words

Total = 1200 words

6.1.7.5.6.8 Repair Time Table - This table is utilized to assure (via crew prompting) that the repair rate exceeds the failure rate. It will provide a time in which a failed LRU should be replaced.

REPAIR TIME BLOCK

CONFIGURABLE ELEMT. ID. (PROC., MEM, DBC, DBT, RDAU, ETC.)	ALLOCATED REPAIR TIME	1 WORD

Memory = 1 word/block x 12 blocks for DMS = 12 words

Redundancy = 12 words

Total = 24 words

6.1.7.5.6.9 Failed Item Table - This table contains the configurable element identification and the time at which the item failed. It is used in conjunction with the repair time table to assure replacement.

FAILED ITEM BLOCK

CONFIGURABLE ELEMENT IDENTIFICATION	RELATIVE SERIAL NO.	TIME OF FAILURE	2 WORDS

Memory = 2 words/block x 10 failure capacity = 20 words

Redundancy = 20 words

Total = 40 words

6.1.7.5.6.10 Auxiliary Storage Allocation Table - This table indicates the utilization and availability of auxiliary storage.

DATA SET NAME	PHYSICAL RECORD CHARACTERISTICS	UNIT ADDRESS	NUMBER OF TRACKS	STARTING TRACK ADDRESS	5 WORDS
10 BYTES	4 BYTES	2 BYTES	2 BYTES	2 BYTES	

Memory = 200 data sets x 5 words/block = 1K words

Redundancy = 1K words

Total = 2K words

6.1.7.5.6.11 Directory Table - This table contains the locations of all tables. For each table there is a double entry due to the redundant storage.

Total memory = 8K words (estimate)

6.1.7.5.7 Executive Services

A three-level software hierarchy has been assumed in this design; i.e., there are individual application programs to check the various equipment within the DMS, there is a checkout executive to perform test scheduling, event initiation, and program restart, and there is a master executive to perform interrupt handling, scheduling of I/O services, and overall task scheduling. The executive services of the OCS and Master executives are:

- OCS Executive
  - Provides asynchronous event initiation; i.e., starting a test at a particular time to assure that the prescribed test rate is met.
  - Provides "configuration control register" management for configuration control purposes.
  - Initiation of tests in portions of the DMS which are outside the operational subset (i.e., in the experiment subset).
  - Provides program restart categorization and restart services.

- <u>Master Executive Services</u>

  - Provides I/O services with specific capabilities to start I/O (SIO), test I/O (TIO), halt I/O (HIO), and test channel (TCH).

  - Perform allocation of main storage resources.

  - Perform allocation of auxiliary storage resources.

  - Provide processor-to-processor READ/WRITE direct communication via the data bus controller.

  - Perform dynamic storage allocation for "save" areas, working storage, etc.

  - Perform data logging function.

  - Provide checkpoints for storage of intermediate program results for system recovery purposes.

6.1.7.5.8 DMS Checkout Sizing Summary

Table 6-6 summarizes the sizing estimates for the various OCS items discussed in previous sections. Some of the items had to be expressed in terms of the number of bytes handled or transferred. To get absolute values for these cases, further assumption would be required.

CPU times were calculated using estimates of the instructions needed to perform each "block" in the flow chart of the program. The time requirements of the instructions were then determined using timing formulas for models of the IBM System/360 and System/4 Pi having similar instruction sets and architecture. These processors had a memory cycle time of 2.5 usec; therefore, the results were scaled by a factor of $1/2.5 = 0.4$ to bring them into line with the baseline processor characteristics, which included a memory cycle time of one microsecond.

6.2 <u>INTEGRATED TEST DEFINITION</u>

The task of ensuring overall Space Station availability is primarily dependent upon the proper structuring of individual subsystem tests. The ability to test the subsystems independent of other subsystems is directly related to the number and types of interfaces. As shown in Figure 6-44, the DMS and Electrical Power Subsystems (EPS) interface with every other Space Station subsystem. In addition, the EC/LS Subsystem provides cooling to most of the electronic packages. This

Table 6-6. DMS Checkout Sizing Summary

Item	Time: CPU Time	Time: I O Time	Storage: Main	Storage: Bulk	Rate	Comments
COM TESTS						
1. CPU PSA Poll	106 ±12 usec	--	30 ±6 words	30 ±6 words	Once per 30 sec	
2. Mem. Address	24,000 ±1600 usec	--	13 ±4 words	13 ±4 words	Once per 30 sec	
3. DBC Wrap	614 ±60 usec	--	94 ±10 words	94 ±10 words	---	
4 DBCs	2458 ±240 usec	--	--	--	Once per 20 sec	
4. DBT Wrap	397 ±40 usec	4096 ±410 usec	98 ±10 words	98 ±10 words	---	
2 DBTs	794 ±79 usec	8192 ±820 usec	--	--	Once per 20 sec	Only 2 terminals are assumed checked at this rate.
48 DBTs	19,064 ±1906 usec	156,600 ±15660 usec	--	--	Once per hour	All other terminals checked hourly.
5. RDAU Tests						
Wrap	224 ±22 usec	14,000 ±1400 usec	38 ±4 words	38 ±4 words	---	
Mem MPX	1711 ±172 usec	1308 ±130 usec	77 ±8 words	77 ±8 words	---	
16 RDAUs	29,360 ±2936 usec	244,800 ±2500 usec	--	--	Once per 20 sec	Only 16 RDAUs are assumed checked at this rate.
117 RDAUs	220,200 ±2000 usec	1,790,000 ±200,000 usec	--	--	Once per hour	All other RDAUs checked hourly.
6. Image Proc.						
Memory	407 +8M ±10% usec	32 +16n ±10% usec	43 + n 4	43 + n 4 words	Once per day	1. n = byte capability of memory.
Display	223 ±22 usec	16 + 8n ±10% usec	50 + n 4	50 + n 4 words	Once per day	2. Performed only by authorization of crew.
7. Bulk Memory						
Tapes	3 ±2 sec	54 ±20 sec	2000 ±1000 words	2000 ±1000 words	Once per day	Crew must authorize and initiate.
Disks	4 ±1 sec	32 ±15 sec	2000 ±1000 words	2000 ±1000 words		
Drum	4 ±1 sec	19 ±8 sec	2000 ±1000 words	2000 ±1000 words		
8. GN&C Preproc.	40 ±20 usec	100 ±30 usec	100 ±50 words	100 ±50 words	Once per 20 sec	
SFI TESTS						
1. Main Memory	884 ±240 msec	--	43 ±5 words	43 ±5 words	---	
2. Sw. Matrix	200 ±160 usec	--	150 ±100 words	150 ±100 words	---	

Table 6-6. DMS Checkout Sizing Summary (cont)

Item	Time		Storage		Rate	Comments
	CPU Time	I O Time	Main	Bulk		
RECONFIGURATION						
CPU	200 ±160 usec	--	200 ±100 words	200 ±100 words	---	
Main Mem.	200 ±160 usec	--	200 ±100 words	200 ±100 words	---	
DBC	32 ±4 usec	--	30 ±3 words	30 ±3 words	---	
DBT	32 ±4 usec	100 ±30 usec	30 ±3 words	30 ±3 words	---	
RDAU	32 ±4 usec	200 ±50 usec	30 ±3 words	30 ±3 words	---	
Bulk	280 ±28 usec	200 ±60 usec	80 ±8 words	80 ±8 words	---	
PROGRAM RESTART						
*Recovery	263 ±80 usec	156 ±78 msec	112 ±18 words	112 ±18 words	---	*Access time to disk = 75 msec (not included in I O time). n = number of bytes transferred.
*Log 1	235 ±24 usec	156 ±78 msec	80 ±8 words	80 ±8 words	---	n = number of bytes transferred.
*Log 2	146 ±102 usec	156 ±78 msec	60 ±6 words	60 ±6 words	---	n = number of bytes transferred.
TABLES		--	32, 844 words	32, 844 words	---	
SFI DISPLAY		--	--	26, 000 words	---	13000 words redundantly stored.

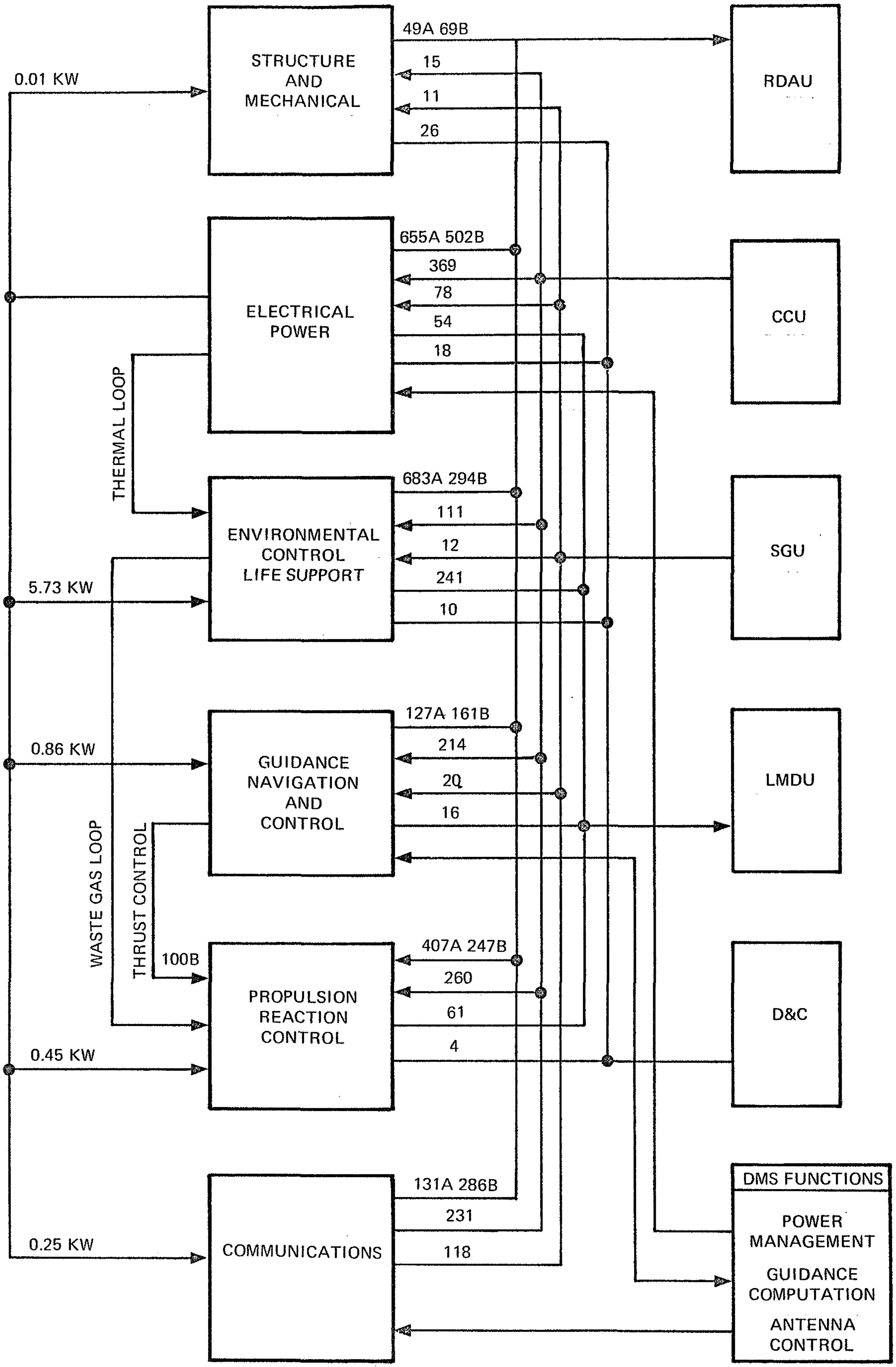


Figure 6-44. Subsystem Interfaces

This situation demands that in constructing the test for a subsystem these interfaces be taken into account so that erroneous or ambiguous test results will not be obtained. In other words, before detailed subsystem fault isolation tests are initiated, a higher level of testing should be performed to verify that all interfaces and Space Station conditions that influence the subsystem are proper. Properly designed, these higher-level tests will (1) indicate what Space Station conditions must be verified, maintained, or changed; (2) localize the malfunction to a single subsystem; and (3) identify the subroutine test necessary for fault isolation.

Since the DMS interfaces with all of the Space Station subsystems and is used as the OCS, it would appear that all of the tests would be integrated. However, this is not a proper interpretation. When the DMS is used to verify the performance of another subsystem, it must first establish itself as a test standard against which the subsystem parameters are compared. Subsequent to this verification, the test is dedicated to the evaluation of the subsystem. This test would be considered as an independent test since the objective of the test was to verify the subsystem and not the DMS. For a test to be considered as an integrated test it must meet one or more of the following conditions:

- Test objectives associated with more than one subsystem
- Test involves subsystem interfaces
- Test requires proper operation of other subsystems

In several cases, the DMS must simultaneously perform the dual role of OCS and functional elements. As an example, the DMS has a functional interface with the GN&C and Prop Subsystems for the computation of guidance equations and the execution of commands to the control actuators. When this functional closed loop is being tested, the DMS must, in addition to performing its normal functions, execute the test routine. For this type of integrated test there must be an intrinsic relationship between the operational and test software. This relationship must be carefully considered in structuring the integrated tests since unstable or intermittent performance may be detected only in the exact operating mode under closed-loop conditions. The number of integrated tests is not extensive due to the approach of minimizing the different types of interfaces between Space Station subsystems. For example, interfaces between the DMS and other subsystems are largely standardized. As a result, relatively common tests can be designed for verification of the multitude of DMS subsystem interfaces or for localization of a fault to one side of a DMS subsystem interface. All special integrated tests that have been identified are discussed in the following paragraphs. The GN&C/DMS/PROP configuration for navigation and attitude control poses the most difficult problem for on-orbit testing so it is presented in significant detail. Other integrated tests are summarized.

6.2.1 GN&C/DMS/PROP

6.2.1.1 Block Diagram

Figure 6-45 shows the block diagram for the GN&C/DMS/PROP Subsystems as configured for the zero g, horizontal mode of operation. The subsystems are shown at the LRU level with all primary functional interfaces. For simplicity, prime power inputs, cold plate interfaces, and mechanical or fluid connections are not shown.

6.2.1.2 Functional Description

The GN&C Subsystem accommodates both the artificial-g and zero-g operations of the Space Station. In the zero-g mode of operation, the GN&C Subsystem provides autonomous navigation, rendezvous command, traffic control, automatic docking, and stabilization and control of the Space Station.

The autonomous navigation scheme utilizes the stellar inertial reference data and the automatic landmark tracker augmented with the drag accelerometer. The navigation is accomplished by automatically tracking known and unknown landmarks several times each orbit. The landmark is similar in operation and mechanization to a gimballed star tracker. The drag accelerometer accounts for anomalies due to Space Station orientation and docked module changes which contribute to navigation errors.

Both ground tracking and onboard subsystems will provide the navigation information for the first year or so of the Space Station Program. The ground-generated data will be transmitted onboard for evaluation of the autonomous navigation system performance. As the confidence in autonomous operation is increased through this parallel operation, the ground tracking is to be phased out.

In all operating modes and orientations, the gyros provide the high-frequency rate and attitude information necessary to supplement the data from the stellar sensors and the horizon sensors.

A more accurate Earth-centered reference is obtained in the horizontal orientation through the use of the strapdown star sensors. The star sensors provide the long-term, drift-free inertial reference data while the gyros provide the short-term, high-frequency attitude and rate information. The passive star sensors are used while the Space Station is maintained in an Earth-centered orientation. The constant rotational rate required of the vehicle to maintain this type of orientation provides the scanning motion for the star sensors, which are completely passive and provide no tracking or scanning capability of their own.

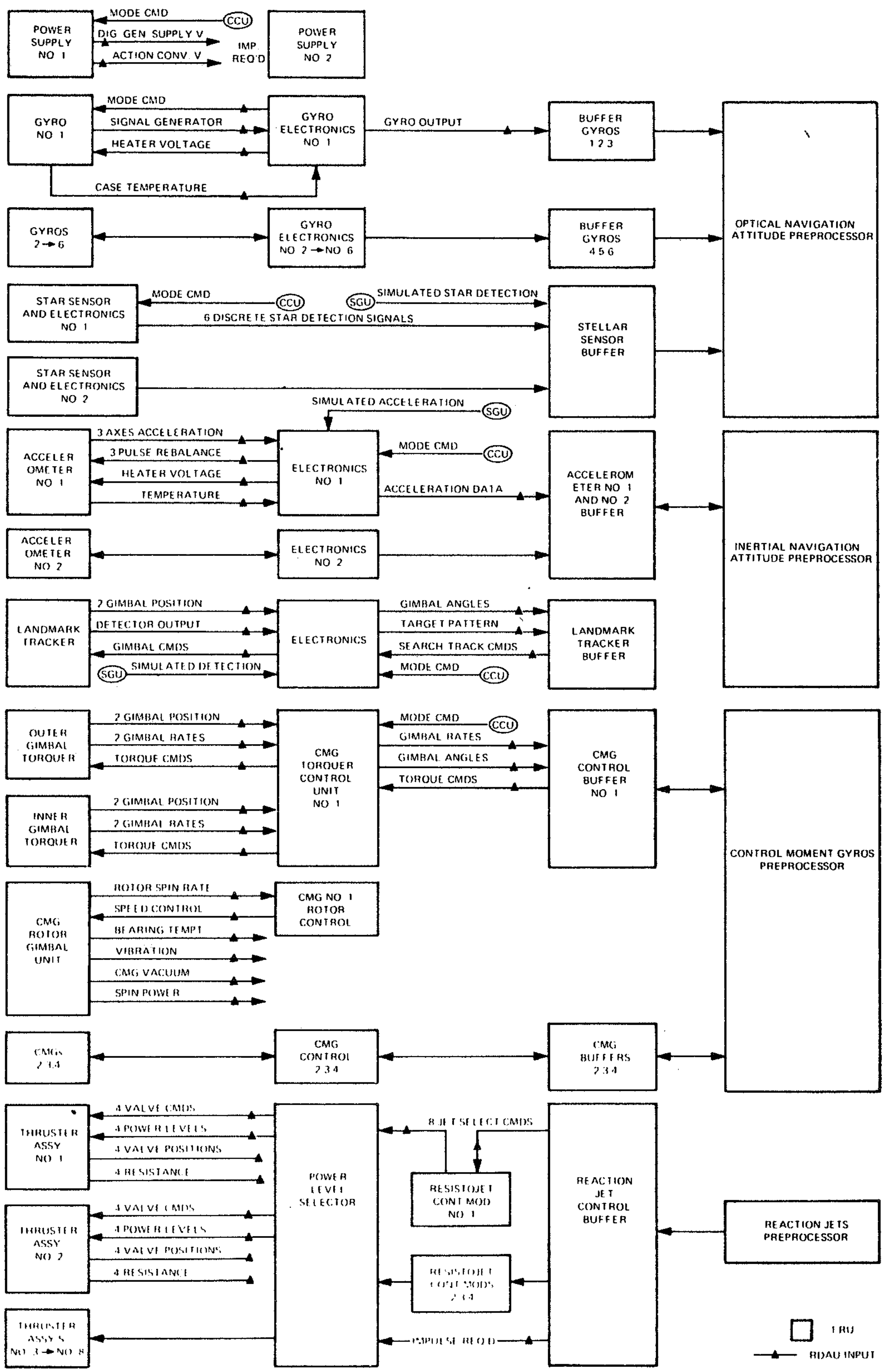


Figure 6-45. GN&C/DMS/PROP Configuration for Zero-G Horizontal Mode

The sensors themselves provide inertial attitude data which is transformed into Earth-centered attitude information by use of the navigation parameters. By this method, both inertial attitude and Earth-centered attitude are derived from the passive star sensors while the vehicle is in the horizontal or other Earth-centered orientation. This Earth-centered orientation is considered to be most responsive to experiment and subsystem requirements.

Primary attitude control actuation is provided by control moment gyros (CMGs). A CMG configuration utilizing four double-gimballed CMGs, each having a momentum capacity of 1,100 ft-lb-sec, was selected for the isotope/Brayton-powered Space Station. Both High and Low-Thrust Propulsion Systems are utilized by the GN&C Subsystem for CMG desaturation and backup attitude control capability. The reaction jet control buffer provides the interface with the Propulsion Subsystem.

The DMS provides the link between the sensors, which are used to determine the vehicle angular position, and the actuators, which are used to maintain or change the vehicle angular position. The use of the DMS provides the flexibility required during both the development and operational phases to accommodate the total Space Station Program objectives. The DMS performs the data processing necessary for all guidance, navigation, and attitude control functions. The interface electronics controls the flow of information from the sensors to the DMS and converts all sensor inputs to a standardized format before the inputs are transferred. The interface electronics performs a similar function for output information from the DMS to the control actuators.

6.2.1.3 Test Flow

The test flow for the GN&C/DMS/PROP configuration is shown in Figure 6-46. The flow demonstrates the technique for malfunction detection, subsystem localization and fault isolation to the LRU. For simplicity some tests associated with prime power, mode commands and cold plate temperatures are omitted. It is assumed that in programming the actual tests these types of measurements will be implemented as standard procedure. In the same vein, detailed tests of the DMS are not shown. Again, it is assumed that the final procedure would contain the necessary self-test, command verification, and other checks to maintain confidence in DMS performance throughout the test.

Many of these test sequences will be repeated for different channels of data or for identical sets of equipment. The test flow does not show the repetition of these tests but indicates the need for them. For example, there are four control moment gyros (CMGs). The flow shows a typical test for one CMG. It should be

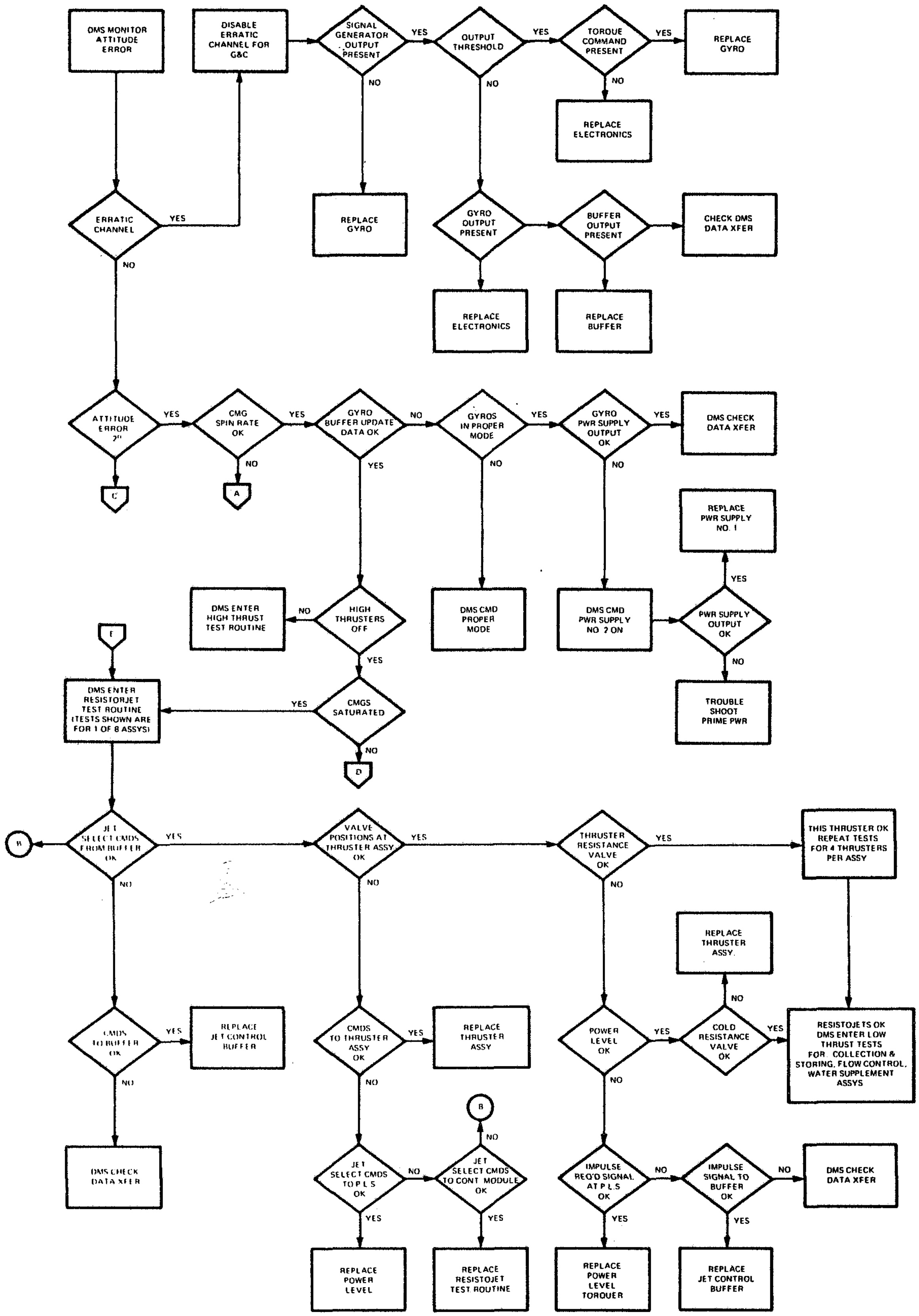


Figure 6-46. GN&C/DMS/PROP Integrated Test Flow (Sheet 1 of 4)

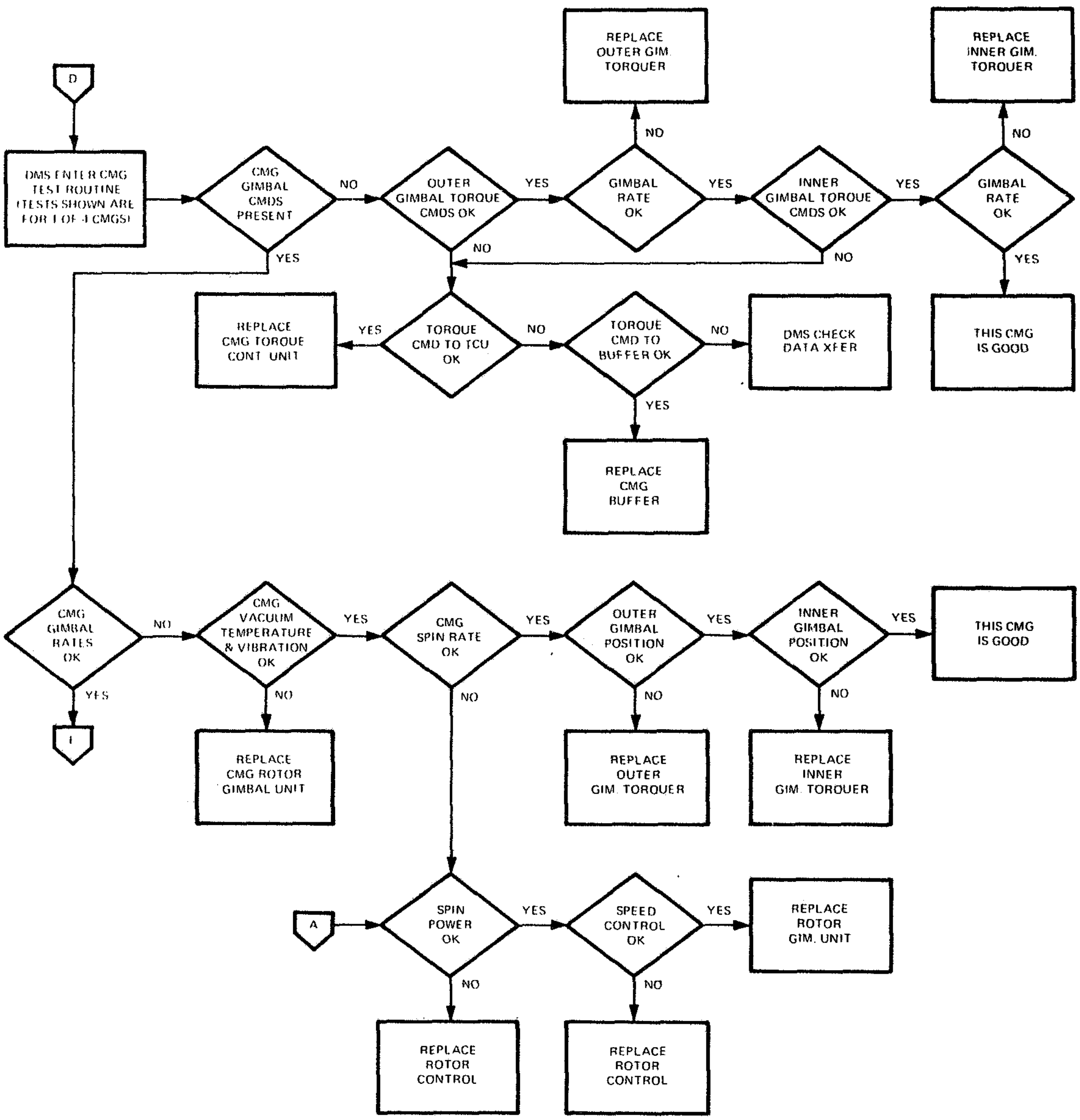


Figure 6-46. GN&C/DMS/PROP Integrated Test Flow (Sheet 2 of 4)

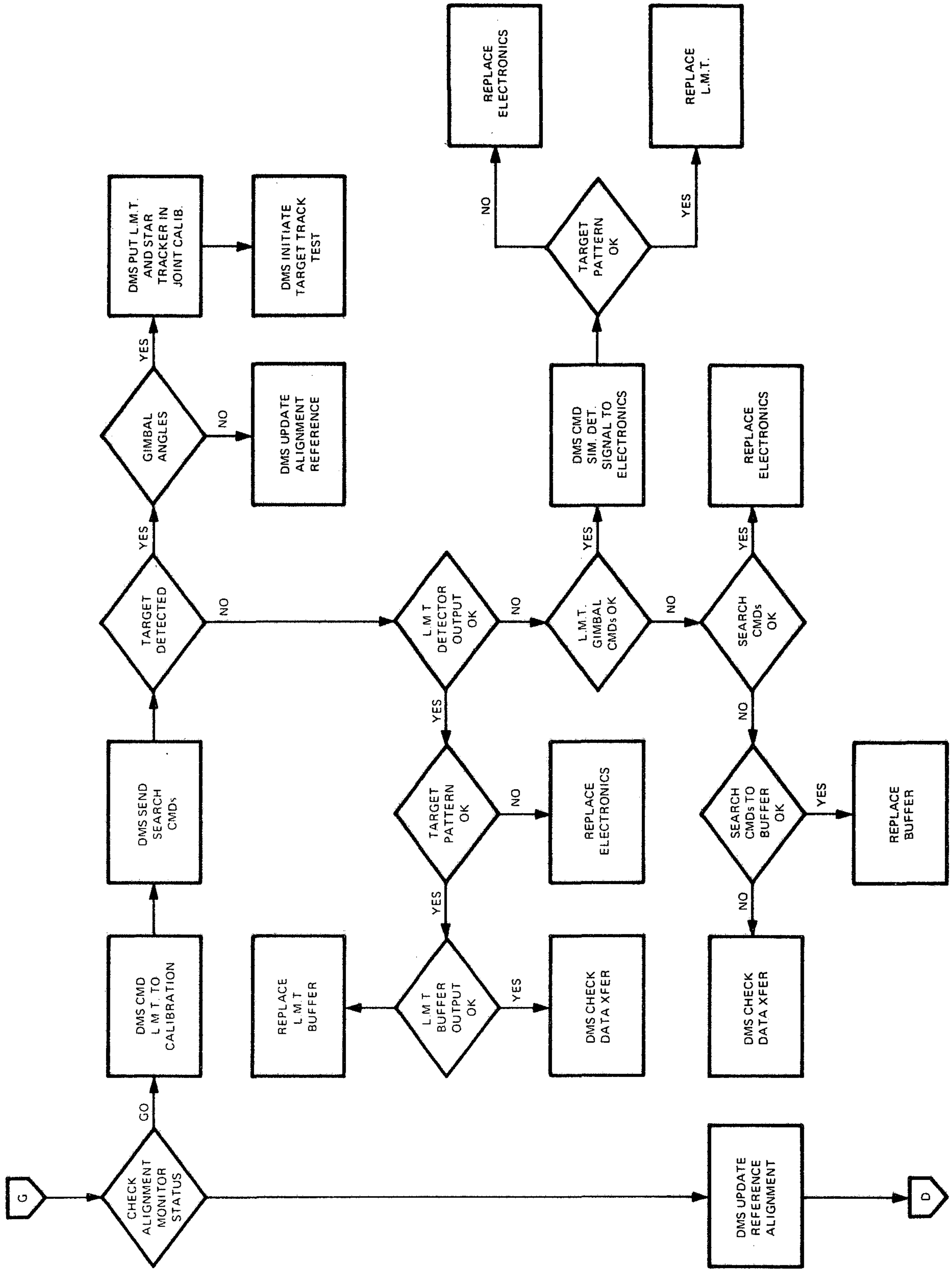


Figure 6-46. GN&C/DMS/PROP Integrated Test Flow (Sheet 3 of 4)

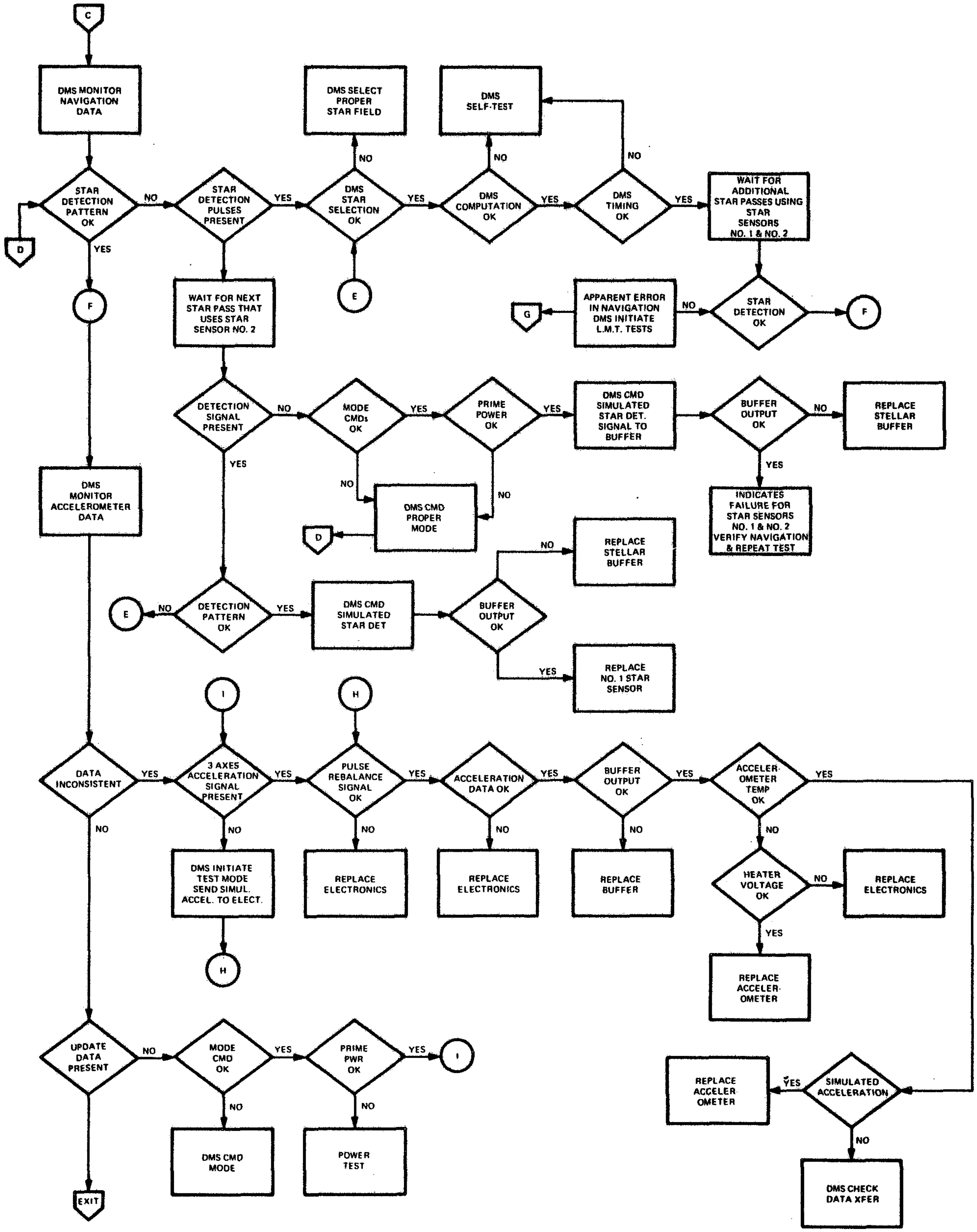


Figure 6-46. GN&C/DMS/PROP Integrated Test Flow (Sheet 4 of 4)

pointed out that although the detail test sequence will be identical for all CMGs, the absolute value of the parameters such as torque commands, gimbal position, gimbal, rates will be different for all CMGs. In some cases, the test flow terminates in an instruction for the DMS to check data transfer. This instruction is intended to include all operations necessary to verify that the DMS is functioning as required to support the operational and test routine.

6.2.2 GN&C/DMS/COMM

The DMS has a functional interface with the GN&C and COMM Subsystems for the pointing and control of antennas. The GN&C sends navigation and attitude information to the DMS which in turn uses it to compute antenna pointing positions and slewing rates. Once computed, the DMS transfers these commands to the antenna actuators in the Communication Subsystem.

Localizing a malfunction to one of the three subsystems will be performed in a manner similar to that described in subsection 6.2.1. The DMS will verify receipt of proper attitude and navigation data from the GN&C Subsystem, check its capability to operate on and transform the data into appropriate antenna commands, and verify the transmission of the control data to the Communication Subsystem. Verification of proper response and operation of Communication Subsystem equipment will be aided by the switching and use of redundant transmitters and receivers.

6.2.3 DMS/EPS

The DMS has a power management interface with the Electrical Power Subsystem. This function primarily includes start-up, control and shutdown of the power conversion equipment, and the control and reconfiguring of the power profile through the distribution buses. Fault isolation is performed by a DMS self-check that verifies proper generation and transmission of control functions to the interface.

The startup, control, and shutdown of the power conversion equipment by the DMS is another example of the integral relationship that must exist between the operational and test software. For example, in starting the Isotope/Brayton System the automatic operational procedure must contain exact instructions for a normal start and an additional set of instructions for aborting or safing an abnormal start. To know the starting sequence (operational software) is not proceeding as planned implies a knowledge of what is wrong (test software). Based upon this knowledge the DMS can execute the appropriate operational controls and identify the malfunctioning element.

6.2.4 GN&C - PROPULSION SUBSYSTEM INTERFACE

The Guidance, Navigation, and Control (GN&C) Subsystem operates in a closed-loop mode with the DMS and Propulsion Subsystem as elements of the loop. Electrical signals to activate appropriate Propulsion Subsystem high thrusters are provided by the GN&C jet drivers based upon control information computed by the DMS. Although the interface between the DMS and the GNC is fairly complex, the GN&C - Propulsion Subsystem interface is not, and can easily be incorporated into tests defined for the Propulsion Subsystem.

6.2.5 EC/LS - EPS ISOTOPE/BRAYTON INTERFACE

The Environmental Control/Life Support (EC/LS) Subsystem interfaces with the EPS Isotope/Brayton System for removal of waste heat via a fluid heat exchanger installed in the Brayton Power Conversion System. It is planned that flow rate, temperature, and pressure parameters be continuously monitored on both sides of the interface as part of normal EPS and EC/LS Subsystem checks.

6.2.6 EC/LS - LOW-THRUST PROPULSION INTERFACES

The EC/LS Subsystem interfaces the low-thrust portion of the Propulsion Subsystem to supply unreacted $C0_2$ from the $C0_2$ removal assembly, methane by-products from the $C0_2$ conversion assembly, and excess water. The Propulsion Subsystem uses these biowaste fluids in the Low-Thrust System as propellant. The interface is controlled by the DMS or by manual control to satisfy such parameters as propellant and pressurant selection. These parameters are primarily a function of impulse requirements and available stores. Checkout of the interface is required to verify proper valve and pump operation for the transfer of the waste gases and excess water.

6.2.7 EPS - SUBSYSTEM INTERFACE

The Electrical Power Subsystem (EPS) supplies power to all assemblies of other subsystems requiring electrical power. Interfaces between the EPS Transmission, Conditioning, and Distribution (TCD) System and other subsystem assemblies are standardized throughout the Space Station. In addition, the tests and associated measurement/stimulus requirements defined for the EPS have indicated that a comprehensive capability exists for checking TCD outputs. Fault localization between TCD assemblies and elements of other subsystems can therefore be accomplished by EPS Subsystem-oriented tests.

Section 7

SOLAR ARRAY CHECKOUT ANALYSIS

7.1 GENERAL

An analysis was made to determine the requirements for onboard checkout of an Electrical Power Subsystem for Space Station containing a solar panel array as the prime power generator. This effort was directed by MSC in addition to the analysis of the isotope/Brayton cycle nuclear power generator in the original study baseline. The solar array power generator analyzed is as described in DRL No. MSC T-575, Line Item 13, entitled "Solar-Powered Space Station Preliminary Design," Volume II. One change was made in the baseline. The fuel cells which were included to provide premanning and emergency power were not analyzed for the following reasons:

1. The study baseline included batteries for this purpose.

2. No source of reactants was available from the study baseline. The fuel cells normally received reactants from the cryogenic attitude control engines. These engines in the study baseline system do not require cryogenic fuels and therefore no source was provided.

The approach taken to this analysis was to identify the changes in study results obtained for the original baseline due to the substitution of a solar array system for each of the subtasks performed on the original baseline subsystem.

7.2 CRITICALITY AND FAILURE MODE ANALYSIS

The changes to the criticality and failure mode analyses prepared for the isotope/Brayton Space Station configuration have been identified. It is assumed that the overall subsystem criticality numbers (complements of the probabilities of achieving full subsystem specification performance for 180 days) are approximately the same for both configurations. Revisions to component-level data are necessary for the Environmental Control/Life Support, Structures, and Electrical Power Subsystems.

7.2.1 ENVIRONMENTAL CONTROL AND LIFE SUPPORT

Changes required in the EC/LS Subsystem are a consequence of removing the subsystem's high temperature water interface with the Isotope/Brayton System. Failure mode and criticality data for added components are provided in Table 7-1.

Table 7-1. EC/LS Additions

Major Subsystem Component	Failure Mode(s)	Mission Effect	Failure Category	No. of Units	(A) MTBF/Source Thousands of Hours	(B) Duty Cycle (%)	Criticality Unit (4380 hrs x B/A x 10^{-6})
Atmosphere Reconditioning							
Valve and Heater Sequence Controller	Open/short in electronics	Eventual loss of CO_2 removal capability	II	8	99/(12)	100	43, 800
Bed Heater	Open/short coil	Eventual loss of CO_2 removal capability	II	8	4545/(12)	100	480
Heater Controller	Open/short	Eventual loss of CO_2 removal capability	II	8	901/(12)	100	4, 850
Urine Water Recovery							
Heater	Open/short coil	Bacteria buildup in H_2O	II	2	4545/(12)	100	480
Heater Controller	Open/short	Bacteria buildup in H_2O	II	2	901/(12)	50	21, 800
Water Storage							
Heater	Open/short coils	Tank rupture. H_2O not sterilized.	II	10	4545/(12)	100	480
Heater Controller	Open/short	Water not sterilized	II	10	901/(12)	100	4, 850
Waste Management							
Heater	Open/short coils	Degraded feces collection and processing	III	4	4545/(12)	12.5	60
Heater Controller	Open/short	Degraded feces	III	4	901/(12)	12.5	610

Deleted EC/LS components are:

2370	Valve sequence controller
3112	Valve temperature bypass
3312	Valve temperature control (hot)
6601	Accumulator
6602	Gas Separator
6603	Filter
6604	Pump/Motor
6605	Check Valve
6606	Relief Valve
6701	Mix heat exchanger

7.2.2 STRUCTURES

Changes in the Structures Subsystem are a result of adding elements to support the solar array power boom. A 42-pound increase in a spares weight is estimated as being required to achieve reliability requirements for the Structures Subsystem. A revised criticality ranking of components is given in Table 7-2. Failure mode and criticality data for added components are provided in Table 7-3.

7.2.3 ELECTRICAL POWER

A criticality ranking of EPS components for the solar array Space Station configuration is provided in Table 7-4. Failure mode and criticality data for the Transmission, Conditioning, and Distribution System are given in Table 7-5. Similar data appear in Table 7-6 for the solar array/battery system.

7.3 MAINTENANCE CONCEPT DEFINITION

Except for the specific maintenance concepts identified for the electrical power source, the maintenance policies and concepts defined for the isotope/Brayton Space Station configuration are also applicable to the solar array configuration. The changes required to the previously defined maintenance concepts to accommodate the solar array configuration have been identified.

7.3.1 STRUCTURES SUBSYSTEM

The reference to the isotope reentry vehicle (IRV) rotation mechanism in the previously defined concepts can be deleted. All other information however is completely applicable to the solar array configuration.

Table 7-2. Solar Array Analysis, Structures Subsystem Criticality Ranking

Component	Single Unit Criticality (10^{-6})	Conditional Loss Criticality (10^{-6})	Remarks
Y/Z Axis Drive and Electronics Interface Unit	14, 450	100	Requires two spares to achieve this conditional loss criticality
X-Axis Drive and Electronics Interface Unit	14, 450	100	Requires two spares to achieve this conditional loss criticality
Bearing Assemblies	1, 400	10	Four spare assemblies and spare bearings can reduce criticality to less than 10
Primary Structure	1, 000	500	Considers that 1/2 the risk can be negated by patching meteoroid penetrations, utilizing makeup 0_2 for leakage, and stopping meteoroids with the meteoroid shield
Radiator	1, 000	500	Considers that 1/2 the risk can be deleted by replacing segments and isolating leaks
Viewport Seals	500	100	Leakage can be made up by emergency 0_2
Tunnel Hatches	500	100	Redundant seals and more than one exit from compartment exists

Table 7-2. Solar Array Analysis, Structures Subsystem Criticality Ranking (Continued)

Component	Single Unit Criticality (10^{-6})	Conditional Loss Criticality (10^{-6})	Remarks
Docking Ports	360	10	Considers repair of docking ports plus capability of docking at any port if one docking mechanism is damaged
Main Airlock	300	10	Replaceable seals and makeup O_2. EVA can also be accomplished via forward section
Antenna Deployment Mechanism	100	10	Provides for less than optimum coverage if one antenna is out and EVA to repair
Fairings	100	10	EVA can release

Table 7-3. Structure Addition

Major Subsystem Component	Failure Mode(s)	Mission Effect	Failure Category	No. of Units	(A) MTBF/Source Thousands of Hours	(B) Duty Cylce (%)	Criticality Unit (4380 hrs x B/A x 10^{-6})
Bearing Assemblies	Freezeup Wear	Cannot rotate panels for optimum sunlight. Loss of partial power.	II	12(thrust) 24 radial 2 torque shaft	1540/(2)	50	1, 400
Power Boom	Structural collapse	Loss of prime power but highly unlikely event.	I	1	--	100	100
Y/Z Axis Drive and Electronics Interface Unit	Hang up Motor open/ short	Loss of portion of EPS power. Less than optimum sunlight positioning.	II	2	30/(12)	10	14, 450
X Axis Drive and Electronic Interface Unit	Hang up Motor open/ short	Non-optimum sunlight positioning. Degradation in power output.	II	2	30/(12)	10	14, 450

Table 7-4. EPS Criticality Ranking

Component	Single Unit Criticality (10^{-6})	Conditional Loss Criticality (10^{-6})	Remarks
Main Inverter Modules	47,000	--	Unknown if spares/redundancy exist. 3 spares are required.
Battery Chargers	4,650	<100	
NiCd Battery	4,380	<100	
Autotransformer	1,800	--	
Solar Array Assembly	1,500	1500	Allows 36% degradation in 10 years
All other components		500	

Table 7-5. Solar Array Analysis

Major Subsystem Components	Failure Mode(s)	Mission Effect	Failure Category	No. of Units	(A) MTBF/Source Thousands of Hours	(B) Duty Cycle (%)	Criticality Unit (4380 hrs x B/A x 10^{-6})
1. Inverter Feeders	Open/Short	Loss of 1/4 power until faulty feeder is replaced.	II	4		100	Neg'l
2. Inverter Feeder Circuit Breakers	Fail to open when overload surge occurs	Same as No. 1.	II	8	14, 300/(4)	100	306
3. Battery Charger Input Circuit Breaker	Same as No. 2	Loss of recharge capability of battery charger.	II	4	14, 300/(4)	100	306
4. Battery Inverter Input and Output Circuit Breaker	Same as No. 2	Loss of portion of power required for experiments. (ac and dc)	II	12	14, 300/(4)	100	306
5. Main Inverter Modules	Open/Short No output	Loss of 1/4 regulated 3 Ø, ac power. Curtailment of experiment until replaced.	III	24	94/(4)	100	47, 000
6. Autotransformers	Open/ Short	Loss of 1/4 60-volt ac to rectifier filter. Ultimate loss of portion of dc & ac voltage to dc & ac load bus. Experiments curtailed.	III	4	2, 460/(2)	100	1, 800

Table 7-5. Solar Array Analysis (cont)

Major Subsystem Components	Failure Mode(s)	Mission Effect	Failure Category	No. of Units	(A) MTBF/Source Thousands of Hours	(B) Duty Cycle (%)	Criticality Unit (4380 hrs x B/A x 10^{-6})
7. Battery Switching Devices	Open/ Short	Less than optimum battery charging/ operation if an individual switching device fails.	III	900	100, 000/(4)	100	44
8. Inverter Input Circuit Breaker	Fail to open when overload occurs	Loss of inverter regulator. Loss of portion of 3 Ø ac power. Eventual curtailment of some experiments.	II	4	14, 300/(4)	100	306
9. Solid-State Switching Devices	Open/ Short	Loss of portion of automatic load and power management control.	III	570	100, 000/(4)	100	44

Table 7-6. EPS-Power Source

Major Subsystem Component	Failure Mode(s)	Mission Effect	Failure Category	No. of Units	(A) MTBF/Source Thousands of Hours	(B) Duty Cycle (%)	Criticality Unit (4380 hrs x B/A x 10^{-6})
NiCd Battery (25 three-cell Modules per battery)	Internal Short Leakage	1. Loss of capability to furnish power during dark portions of orbit, however, redundancy is provided. 2. Can't meet peak power demands.	II/III	12 Batteries of 25 3-cell Modules each (12 spare Modules)	2, 000/(4)	100 (Includes charge and discharge cycle)	4, 380
Battery Chargers	No Output Open/ Short	No immediate effect. Same as above eventually.	II/III	12	470/(2)	50	4, 650
Battery Switching Unit	Open/Short	Same as for batteries except manual override capability exists.	II/III	12	10, 000/(8)	10	44.
Cold Plates	Leakage	Battery overheats. Life is shortened.	III	12	10, 000/(12)	100	440.
Solar Array Assembly (4 panels)	Open/Short of Individual Solar Cell	Partial loss of power output.	II/III	4	.068 for 740, 000 cells	50	1500 (allows 36% of cells to fail)
Bi-stem actuator	Open/Short	Solar panel not deployed, partial loss of power.	II	4	80		

Maintenance of the solar array deployment and orientation system is planned through providing an on-orbit removal and replacement capability for such LRUs as the redundant axis drive units, turret head radial and thrust bearings, main torque shaft roller bearings, and the inflatable seals for the turret head and torque shaft. Although seal replacement requires IVA, the other replacements noted can be accomplished in a shirtsleeve environment. Replacement of the support boom unfold and lock actuators requires EVA, but the need for this activity is extremely remote.

A capability for replacing the entire Space Station power boom module is provided in the NAR baseline design. The probability of utilizing this capability would be extremely remote if individual solar panels were designed for replacement. Without this feature, there is a high risk of needing a new boom before the expiration of 10 years.

7.3.2 ELECTRICAL POWER SUBSYSTEM

The major Electrical Power Subsystem (EPS) maintenance activity for the solar-array Space Station is associated with the replacement of components such as power contactors, switches, inverters, battery chargers, and battery modules. Hardware that is expected to experience failure is modular and redundant with offline spares switched in when a failure occurs.

The battery module is the basic maintenance unit of the battery and is capable of being removed and replaced by the crew while in orbit. Each battery has provisions for bypassing a failed cell, sensing voltage, temperature, and pressure, and a load resistor for conditioning of an individual cell. This concept allows three cell failures per battery before maintenance or replacement is required. The individual cell control approach permits automatic bypassing of failed cells with battery operation continuing on the remaining "good" cells. Failed cells are replaced after the fourth cell fails in any of the twelve 75-cell batteries. Replacement is at the three-cell module level. It is planned that all cells be replaced after 2.5 to 3 years operation.

Although the replacement of individual solar panels or solar panel segments is not possible in the present design, the Space Station's long duration mission makes the provision of this capability highly desirable. It is assumed for purposes of this study that individual solar panels are replaceable. This is considered necessary since the original design has been modified in this study to exclude the fuel cells. One function of the fuel cells was to provide power when the entire power boom was being replaced. This function is not required if a lower level maintenance capability is provided. Replacement of individual solar panels and bi-stem actuators requires EVA, of course, but this is a very infrequent activity.

7.4 SUBSYSTEM CHECKOUT STRATEGY

The subsystem and integrated subsystem checkout functions identified and analyzed for the isotope/Brayton Space Station configuration are largely applicable to the solar array configuration. Checkout functions identified for other subsystems and integrated subsystems are not affected by the new solar array configuration. The previously identified sensing requirements for the Environmental Control/Life Support and Structures Subsystems are affected, of course, and the necessary revisions are included in changes to the measurement/stimulus lists.

7.4.1 ELECTRICAL POWER SUBSYSTEM

The Electrical Power Subsystem (EPS) consists of power conversion assemblies and a power control and distribution network. The power conversion assemblies consist of solar arrays and batteries for prime power. The batteries are also used for premanning and emergency power. The control and distribution network consists of battery chargers, rectifier filters, autotransformers, inverter-regulators, solid-state circuit breakers, power contactors, and primary and secondary bus structure.

The EPS encompasses a wide variety of equipment including electrical, electronic, and mechanical systems. This results in a diversity of checkout requirements.

7.4.1.1 Stimulus Generation

Stimulus generation requirements imposed by the EPS are relatively few and simple. These consist of simulated current unbalance inputs required to periodically test the operation of differential protection relays, and mode-select inputs to the inverters and battery chargers.

7.4.1.2 Sensing

Sensing requirements imposed by the EPS are shown in detail in the measurement/stimulus list. A major portion of the EPS measurements are attributed to battery measurements required by a per-cell approach to battery management. Included are measurements for cell pressure, temperature, voltage, and those required for cell reconditioning, cell by-pass, and detection of failed cells.

Measurement sensor and transducer requirements are generally well within current instrumentation capabilities. Sensor outputs are directly measureable as a dc voltage within specified ranges, or are converted to standard measurement voltages by signal conditioning circuitry.

Selected sensors are implemented redundantly due to the criticality of the measurement or to the difficulty of replacing a failed unit. Critical parameters with redundant instrumentation include array blanket temperature and main shaft bearing temperature. These redundant sensors provide the opportunity to perform cross correlation and calibration of measurements.

7.4.1.3 Signal Conditioning

Signal conditioning is required for all sensor outputs which do not fall within the standard measurement capability of the DMS remote data acquisition units. The requirements include strain gage, temperature probe conditioning networks, ac-to-dc converters, and frequency-to-dc converters. These devices perform signal conversion and scaling as necessary to provide a standard output to the Data Acquisition System.

7.4.1.4 Limit Checking

Limit checking routines are highly applicable to the EPS. These are used to verify that critical parameters such as battery cell temperatures and pressures, and solar array orientation and boom tip deflections remain within given tolerances. Limit tests are utilized within the Power Distribution System to monitor bus voltages and currents and to verify the settings of automatic circuit protection devices such as percentage differential protection relays.

7.4.1.5 Trend Analysis

Opportunities to apply trend analysis techniques to a solar array/battery EPS are evident for both short-term and long-term trends. Meaningful trend data may be obtained from selected temperature measurements in equipment items throughout the EPS and from system voltages. The former includes heat sink temperatures in equipment such as autotransformers, inverters, and battery cells. These are relatively short-term trend parameters and may provide indications of degradation or incipient failure. Long-term trend parameters include load sharing and voltage regulation of inverters, current-voltage (IV) characteristics of each solar array circuit, and battery voltage. The long-term parameters are used to identify and project efficiency and output degradation in these assemblies.

7.4.1.6 Fault Isolation

Fault isolation is accomplished through comparison of measurement operating conditions and predetermined limits and by combinational analysis of input/output measurements and associated performance parameters. Redundant element substitution is also used where available.

7.4.2 REDUNDANT ELEMENT CHECKOUT

Hardware that is expected to experience failure is modular and redundant in the sense that off-line spares are turned on automatically when failures occur so that no loss of operation is experienced. Redundant elements in the EPS include protection and switching devices for critical loads, 60-Hz inverters, 400-Hz inverter output modules, and battery cells. Checkout of the redundant units is accomplished by switching them on-line periodically and verifying proper functioning under normal operating conditions. A special situation exists in the case of the 60-Hz inverters for the general purpose loads (GPL), assuming they do not operate in parallel. Periodic checkout of these units would then require a dummy load to substitute for the GPL loads in order for testing to be performed without interrupting GPL operation.

7.4.3 INTEGRATION WITH DATA MANAGEMENT SUBSYSTEM

Stimulus requirements in the EPS involve primarily fixed value currents or voltages associated with operation or testing of power conditioners and circuit protection devices. These devices are concentrated at the main power centers. They generally do not require unique or sophisticated stimuli. This combination of conditions favors external rather than built-in stimulus generation. A requirement is therefore imposed on the DMS to generate these stimuli and to control their application to the appropriate EPS test points.

The design employs solid-state load control and circuit breaker units in the power distribution feeders for the individual loads. These units provide automatic protection against overloads, but are under DMS computer control for all other load power switching functions. The logic and decision functions are presumed to be furnished by the DMS. This creates a difficult subsystem integration task because of the lack of concise interface definition. These EPS-DMS interfaces are excluded from the present analysis, not simply for lack of interface definition, but rather for compatibility with the isotope/Brayton analysis. In the isotope/Brayton study it was assumed that load power on-off switching would be accomplished in the load subsystems; manual magnetic circuit breakers were assumed for load feeder applications, with separate provisions for remote switching of emergency/essential loads to alternate supply buses as required.

A minimum of two remote data acquisition units are required to operate in conjunction with the solid-state circuit breaker, the built-in test, and operational parameters of the secondary bus structure. Fully automatic protective and corrective controls, including problem-solving, are a function of the DMS. The complex control-protective functions are absolutely dependent on the DMS computer.

Not all automatic functions are controlled by the DMS. Battery charger logic functions such as end-of-charge cutoff, over pressure and over-temperature cutoff, temperature compensation of charging voltage, and cell and module bypass control are handled locally by the charger control unit.

Measurement sensors, transducers, and signal conditioning for the EPS are provided as an integral part of that subsystem. The signal interface between the EPS and the DMS is in the form of a dc voltage for each measurement. The voltage levels are in the ranges of 0-20 mv, 0-5 v, and 0-28 v.

7.5 LINE REPLACEABLE UNIT DEFINITION

The definition of line replaceable units (LRUs) prepared for the isotope/Brayton Space Station configuration is valid for the GN & C, Propulsion, and RF Communications Subsystems in the solar array configuration. It also is largely applicable for the Structures and Environmental Control/Life Support (EC/LS) Subsystems. The LRU listing for the Electrical Power Subsystem (EPS), however, was completely revised to reflect the solar array configuration.

7.5.1 ENVIRONMENTAL CONTROL AND LIFE SUPPORT

Changes required in the EC/LS Subsystem are a consequence of removing its high temperature water interface with the Isotope/Brayton System. Removal of this interface eliminates the need for the heating water portion of the thermal control system and its interfaces with other EC/LS systems. The change, however, does require the addition of heaters and heater control elements in these other systems which include the CO_2 removal assembly of the Atmosphere Reconditioning System, the urine water recovery and water storage assemblies of the Water Management System, and the fecal collection assembly of the Waste Management System. Affected LRUs and their quantities for both the isotope/Brayton and the solar array configurations are shown in Table 7-7.

7.5.2 STRUCTURES

The definition of Structures Subsystem LRUs provided for the isotope/Brayton Space Station configuration is also valid for the solar array configuration. There are, however, additional LRUs required in the Structures Subsystem to support the solar array power boom. These are delineated in Table 7-8.

7.5.3 ELECTRICAL POWER

A complete revision of the original LRU definition for the Space Station Electrical Power Subsystem (EPS) was necessary for the Solar Array Power System. The EPS LRU identification for the solar array configuration is segmented into two parts. The first is concerned with EPS transmission, conditioning, and distribution equipment while the second addresses the solar array/battery system.

Table 7-7. Solar Array Analysis - EC/LS LRU Changes

LRU	Quantity		Change
	I/Br	Solar	
Three-way Valve, Electrically Operated	34	26	- 8
Electric Heater	20	30	+10
Check Valve	40	36	- 4
Pump	40	36	- 4
Temperature Controller	7	31	+24
Four-way Valve, Electrically Operated	26	18	- 8
Pressure Relief Valve	22	18	- 4
Valve Sequence Controller	2	0	- 2
Valve and Heater Sequence Controller	0	2	+ 2
Gas-Liquid Separator	14	12	- 2
Temperature Control Valve	26	24	- 2
Coolant Accumulator	12	10	- 2
Coolant Water Filter	24	20	- 4
Liquid-to-Liquid Heat Exchanger	13	12	- 1
Total Net Change			- 5

7.5.3.1 Transmission, Conditioning and Distribution

The transmission/conditioning/distribution (T/C/D) design defined for the solar array power generator requires the following minimum modifications for compatibility with the study baseline subsystems.

- Change the output voltage of the rectifier-filters from 56 vdc to 28 vdc.
- Increase the dc power output capability and reduce the ac power output capability to reflect the lower ac-to-dc power ratio for the MDAC loads.
- Delete the double ac buses (416 vac).
- Add a 60-Hz 115-vac single-phase power capability for loads in the GPL.

The EPS T/C/D LRUs are listed in Table 7-9.

Table 7-8. Solar Array Analysis - Structures LRU Additions

LRU	Quantity
Support Boom Unfold Actuator	2
Support Boom Lock Actuator	2
Thrust Bearing Assembly	12
Radial Bearing Assembly	24
Turret Head Lockout Block	12
Torque Shaft Inflatable Seal	2
Turret Head Inflatable Seal	1
Y/Z Axis Drive and Electronic Interface Unit	2
X-Axis Drive and Electronic Interface Unit	2
Torque Shaft Roller Bearing	2
Space Station Power Boom (Complete Module)	1

The components mounted on the secondary bus structure are considered LRUs and are designed for removal and replacement. Only the solid-state circuit can be installed or removed with the circuits of the secondary bus energized. Replacement of an auto transformer or rectifier filter is not expected to be required in a ten-year period of operation.

The boom inverter (solar array power) and the core inverter will be of modular design having input, control, and output modules. The modules are replaceable in orbit should a malfunction occur. With proper design, the inverters would be interchangeable between the two locations with a change in input modules.

Contactors and solid-state components are used for power control. Where large currents have to be handled, contactors are used because of the limited ratings and large voltage drop inherent in solid-state devices. Solid-state load control and circuit breaker units are used for the individual loads; therefore, smaller contactors (ratings of 20 amperes and below) will not be required. Space provision for spare circuit breakers is included in the secondary bus structure.

Table 7-9. Solar Array Analysis - EPS T/C/D LRUs

LRU	Quantity Required	Quantity Redundant
Boom Inverter Feeders	4	
Boom Inverter Feeder Power Contactors	4	
Boom Inverter Feeder Differential Protection Relays	12	
Primary Bus Differential Protection Relays	12	
Primary Bus Tie Cables	4	
Primary Bus Tie Power Contactors	4	
Battery Charger Input Power Contactors	12	
Core Inverter Input Power Contactors	4	
Core Inverter Output Power Contactors	4	
Autotransformer Input Power Contactors	4	
Battery Charger Modules	12 (TBD)	1
Boom Inverter Modules (4 x 6 at 2.5 kw)	23	1
Core Inverter Modules (4 x 3 at 2.5 kw)	11	1
Autotransformer	4	
Autotransformer Differential Protection Relays	12	
Secondary Bus Main Power Contactors	8	
Rectifier - Filter	4	
Solid-State Circuit Breakers (28 vdc/120 vac SSSDs)	TBD	yes - TBD
60-Hz 115-vac Single-Phase Inverter (for GPL)	(Est. 570) 1	(For redundant loads) 1
Power Control Modules	TBD	TBD
Instrumentation Sensors/Signal Conditioning	TBD	TBD
Main 60-Hz Distribution Bus Power Switches (Single Pole)	2	

Table 7-9. Solar Array Analysis - EPS T/C/D LRUs (Continued)

LRU	Quantity Required	Quantity Redundant
60-Hz Bus Line Cable (Single Phase)	1	1
60-Hz Bus Line Cable Circuit Breaker	1	
60-Hz Feeders to Distribution Panel (GPL Only)	1	1
60-Hz Distribution Feeder Circuit Breakers (GPL Only)	10	
60-Hz Bus Sectionalizing and Load Line CBs (GPL Only)	10	

7.5.3.2 Solar/Array Battery

For compatibility with the study baseline subsystems, the fuel cells have been removed from the design. The EPS analyzed, therefore, employs two basic kinds of power sources for meeting Space Station power requirements. These are: (1) the solar arrays for the light period of each orbit and (2) batteries for the eclipse periods and for power peaking.

The solar array is comprised of four independent rollup solar panels, each of which is made up of 40 electrical circuits. The panels are overdesigned at beginning of life to allow for approximately 36 percent degradation. Replacement of the solar array requires full replacement of the Space Station power boom. The capability for replacing individual panels or panel segments is not indicated in the present solar array design. Although the reliability of the solar array complex is relatively high, the assumption is made that the long duration mission justifies being able to replace at least solar panels individually.

The battery assembly consists of a group of battery modules, battery racks or enclosures, and control units. The batteries are sealed nickel-cadmium space batteries designed for 100-ampere hour capacity and consist of 25 three-cell modules connected in series or a total of 75 series-connected cells. Three of the 75 cells or one module is included in each of 75 cell batteries as a spare. The EPS requires twelve such batteries.

A listing of the solar array/battery LRUs is given in Table 7-10. Their selection is predicated upon life and reliability considerations as well as previously defined maintenance concepts. Maintenance is restricted to those assemblies and components which are within the scope of projected crew skills and available tooling.

Table 7-10. Solar Array Analysis EPS Solar Array/Battery/LRUs

LRU	Required	Standby Redundant
Solar Panels	4	0
Batteries	12	0
Battery Module (25/Battery)	300	12
Bi-Stem Actuators	4	0

7.6 SUBSYSTEM TEST DEFINITIONS AND MEASUREMENT/STIMULUS LISTS

Changes to the subsystem test definitions and measurement/stimulus lists prepared for the isotope/Brayton Space Station configuration have been defined to reflect the solar array Space Station configuration. The data for the GN & C, Propulsion, and RF Communications Subsystems are not affected by the new configuration. Table 7-11 is a summary of the measurement and stimulus requirements for the Solar Array Space Station.

7.6.1 ENVIRONMENTAL CONTROL AND LIFE SUPPORT

Environmental Control and Life Support (EC/LS) Subsystem changes are a consequence of: (1) removing the subsystem's high temperature water interface with the Isotope/Brayton System, and (2) adding heaters and heater control elements to certain EC/LS assemblies. Measurements and stimuli that apply only to the isotope/Brayton configuration are delineated in Appendix I-10(a). Additional measurements and stimuli required for the solar array configuration are noted in Appendix I-10(b). The previously submitted EC/LS Subsystem test definition is not affected by these changes.

7.6.2 STRUCTURES

The definition of Structures Subsystem tests provided for the isotope/Brayton Space Station configuration is also valid for the solar array configuration. There are, however, additional checkout activities required to support the solar array power boom. Changes to the previously submitted Structures Subsystem measurement/stimulus list are given in Appendix I-10(c).

Table 7-11. Measurement/Stimulus Summary — Solar Array Configuration

SUBSYSTEM	STIMULUS					RESPONSE				STATUS MONITORING							
	Analog	Bilevel	Digital	Pulse	RF	Analog	Bilevel	Digital	Total	Non-Critical	Caution	Warning	Periodic Checkout	Cali-bration	Trend	Fault Isola-tion	Remarks
Guidance, Navigation and Control	20	146	62	6		127	161	70	592	130	16		516	74	74	592	
Propulsion - Low Thrust		134				120	124		378	152	14		378	48	8	378	
Propulsion - High Thrust		126/62				287/117	123/63		536/242	80/28	33/15	14/10	536/242	259/111	117/43	482/222	Art-g/Zero-g periods
Environmental Control/ Life Support	34	111				691	280		1116	139	205	32	1116		135	1116	172 Caution/Warning Signals are for IVA/EVA
RF Communications	37	206	36		77	131	286	28	801	58			576	24	93	801	
Structures	15/16	21/19				60/53	75/66		174/154	7			123/104			174/154	
Electrical Power - TCD	52	1952				292	1292	20(1)	7608	1404	20		724		134	3608	(1) Twelve of these take pulse form
Electrical Power - Solar Array/Battery		1916				4044	928		6780	3704	12		2184		332	6788	
Data Management			53			33	188	83	357	357			62	62	62	357	
Total	151/169	4512/ 4446	151	6	77	5785/ 5628	3457/ 3388	201	14,350/ 14,035	6031/ 5979	300/282	46/42	5110/ 5902	467/ 319	935/ 861	14,266/ 14,016	

Parameters to control and monitor proper folding and unfolding of the arrays receive only an operational assessment. This event-oriented function is expected to occur very infrequently.

A periodic power check of the X-axis and Y/Z axis drive units is conducted at the start of each shift. A thorough check and visual inspection of power boom operation are expected to be required every three months. The power boom is pressurized during this check, and continuous monitoring of boom temperature and pressure is required.

7.6.3 ELECTRICAL POWER

A complete revision of the previously submitted test definitions and measurement/stimulus lists for the Space Station Electrical Power Subsystem (EPS) was required. The EPS Transmission, Conditioning, and Distribution System (TCD) is addressed first, followed by the Solar Array/Battery System.

7.6.3.1 Transmission, Conditioning, and Distribution

The TCD System requires a minimum amount of crew supervision. This is indicated by the limited number of operational parameters required. Operational parameters consist of core and boom inverter power output readouts, battery status, and ac and dc secondary bus voltages. The inverter power readouts establish the degree of load balance between the operating units. A small amount of unbalance will normally be present whether the inverters are operating in a parallel mode or isolated. Crew action is required only if normal limits are exceeded (as detected by the Power Management Assembly), or if high experiment activity requiring maximum possible sustained power is imminent. Crew response under these conditions is to maximize inverter loading by isolating selected primary buses and/or by selective transfer of loads.

Battery status displays and readouts of selected bus voltages provide additional information for evaluating system performance and capability for accepting additional load. The ability to call up the status of any other system element, as may be deemed necessary for evaluation of a particular operational condition, provides the flexibility required to ensure adequate status assessments at any given time.

All circuit breakers and contactors for power transmission lines, source and distributor buses, and power conditioning equipment can be remotely controlled. Many are controlled by signals from automatic protection equipment such as differential relays. Remote control is also required to provide for either manual or programmed reconfiguration of the TCD System following automatic fault-clearing operations, as well as for facilitating reconfiguration to match changing load or other operational conditions. Additional controls are provided to support checkout functions.

No capability was shown in the isotope/Brayton configuration for remote control of individual circuit breakers in the distribution circuits to the loads. It was assumed that all switching of loads would be accomplished in the load systems themselves rather than by opening and closing circuit breakers in the power lines to individual loads. This assumption was made since final definition of load switching control design was not yet developed. This is in contrast to the solar array configuration which uses solid-state switching devices (SSSDs) for this purpose.

7.6.3.1.1 Status Monitoring

Continuous monitoring is required to detect out-of-tolerance conditions for parameters such as inverter load-sharing, principal bus voltages, and equipment temperatures, and also to detect abnormal events. These include relay trips, circuit breaker and contactor trips, and loss of inverter sync signal. Sampling rates generally correspond to those specified for the Isotope/Brayton System for analogous functions.

Boom and core inverter power output, operating currents and 60-Hz inverter bus voltages are sampled at the rate of six per minute. This rate should eliminate the effects of transients (assuming a fault signal is generated only if an out-of-tolerance condition is sensed in two consecutive samples), while still providing a reasonable response time for follow-on corrective action. A sampling rate of once per second is specified for bus voltages. This assures minimum delay in detecting out-of-tolerance voltages at the load interfaces. For this higher rate, abnormal voltage should be sensed in a minimum of five consecutive samples before a fault signal is generated.

Equipment temperatures are sampled at a rate of four per hour. Considering thermal lags inherent in the equipment being monitored, this rate should be adequate for all but catastrophic failures.

Secondary bus differential relay trips are monitored at a one sample per minute rate. The corresponding power contactor trips are sampled at a rate of two per minute. If a contactor trip is not indicated in either of the first two samples following a relay trip, it is presumed the contactor will not operate to clear the fault, and alternate corrective action is immediately taken. Battery charger input contactors are also sampled at a rate of two per minute.

Boom inverter feeder and primary bus differential relay trips are sampled at a rate of one per second. This is because operation of these relays results in tripping the associated boom inverter contactor, with a consequent loss of one-fourth the station primary power source capacity. The sampling rate for the boom inverter contactors is five per second. These relatively high rates are required to minimize system and load disturbances in switching to a backup mode of operation. A sampling rate of five per second is chosen for the core inverter contactors since the loss of one of these units also results in a one-fourth reduction in station source capacity.

No life-critical functions have been identified for the TCD System. An unscheduled opening of a core or boom inverter or autotransformer contactor, however, results in loss of one-fourth of the primary power source and is therefore listed as a caution function.

7.6.3.1.2 Periodic Checkout

Checkouts will be performed at intervals ranging from once per week to once each six months depending on equipment or parameters to be checked. These can be summarized as follows:

Equipment or Parameter	Checkout Interval
Cable currents Bus volts 60-Hz inverters Battery chargers	Once per week
Core and Boom Inverters Autotransformers Secondary Buses Rectifier - Filters	Once per month
Power Contactors	Once each three months
Differential Protection	Once each six months

The principal tests required to ensure TCD System performance, integrity, and availability are listed in Table 7-12. In addition to these tests, checks of selective switch positions, interlocks, and system load distribution are required. Tests for relay, circuit breaker, and contactor operations can generally be

Table 7-12. Transmission Conditioning and Distribution System Periodic Tests (Solar Array Space Station)

Test	Rationale
Protective Relay Operation	To verify proper operation of protective devices
Circuit Breaker and Contactor Operation	To verify remote operability of breakers and contactors
Inverter Module (Internal) Switching	To determine inverter response to control inputs
Battery Charger Mode and Module Switching	To determine charger response to control inputs
Inverter Synchronizing and Paralleling	To assess performance of automatic (internal) circuits
Inverter Load Sharing	To assess performance of automatic (internal) circuits
Power Conditioning Equipment Parameters	To determine nominal performance capability and degradation, if any, with respect to like units
Bus Voltages	To assess general health of TCD System

accomplished on-line during periods of relatively low-scheduled experiment activity; system switching effects will be minimal. Testing of input and output contactors for the boom inverters can be accomplished without power interruptions by scheduling tests during dark periods when power is not available from the solar arrays. Battery charger contactors can also be tested during dark periods. Core inverter contactor testing can be scheduled for sunlight periods when full power is available from the arrays. No major shock-producing tests, such as power line faults or fault clearing, are planned.

Complexity of checkout varies from simple readouts of parameters, such as voltage or temperature, to injection of test currents into current transformer loop circuits to simulate fault conditions seen by protection relays. An example of a procedure which typifies the range of parameter testing and also tests the module switching circuits provided for power matching is given in Table 7-13 for the core inverters.

Table 7-13. Periodic Checkout Core Inverters (Schedule During Sunlight Periods)

1. Open inverter input and output power contactors.
2. Inhibit closure of output contactor.
3. Switch battery charger off (internal).
4. Close inverter input power contactor.
5. Monitor inverter frequency (free running).
6. Monitor open-circuit output voltage levels, phase angles, and waveforms for harmonic content.
7. Apply synchronizing signal to inverter.
8. Monitor inverter frequency (clock controlled).
9. Repeat Step 6.
10. Enable closure of inverter power output contactor.
11. Monitor inverter output for paralleling transients at contact closure (paralleling is automatic).
12. Measure inverter phase power outputs, frequency, phase currents, phase voltages, phase angles, power factor, and harmonic content; measure input voltage and current.
13. Measure load division among operating inverters.
14. Command turn on of additional core inverter module; monitor change in core inverter input and output power.
15. Command turn off of module turned on in Step 14; monitor change in core inverter input and output power.
16. Return to pre-test conditions.

7.6.3.1.3 Calibration

No requirements for calibration are listed; however, a limited amount of calibration may be required for certain relay installations. This requirement is yet to be determined.

7.6.3.1.4 Trend Analysis

A limited amount of trend analysis is necessary for TCD parameters. The sampling rate for parameters monitored for this purpose is as follows:

Trend-Monitored Equipment or Parameters	Sampling Rate
Cable currents	Four per hour
Inverter output power	
Bus voltages	
Rectifier-Filter input voltage	
Rectifier-Filter output current	
Equipment temperatures	Four per day

7.6.3.1.5 Fault Isolation

Control signals for opening and closing remotely operable circuit breakers and contactors are required for fault isolation. These signals are operated internal to the TCD System (e.g., differential protection sensing and relay output) to provide coordinated automatic fault clearing, and external to the system for preprogrammed operations and checkout purposes. A typical fault isolation flow diagram is given in Figure 7-1.

7.6.3.2 Solar Array/Battery Source

The EPS power source employs: (1) a solar array for light orbital periods and (2) batteries for eclipse periods and to accommodate peaking and emergency requirements. The solar array configuration consists of four flexible rollout solar panels attached to cylindrical storage drums. Each drum is attached to a common support structure which mounts to a bi-stem deployable boom actuator. The total array area is 10,000 ft^2 or 2,500 ft^2 per panel. Each panel is made up of two flexible blankets on which solar cells are attached. Each blanket contains 20 solar cell circuits for a total of 160 circuits in the array.

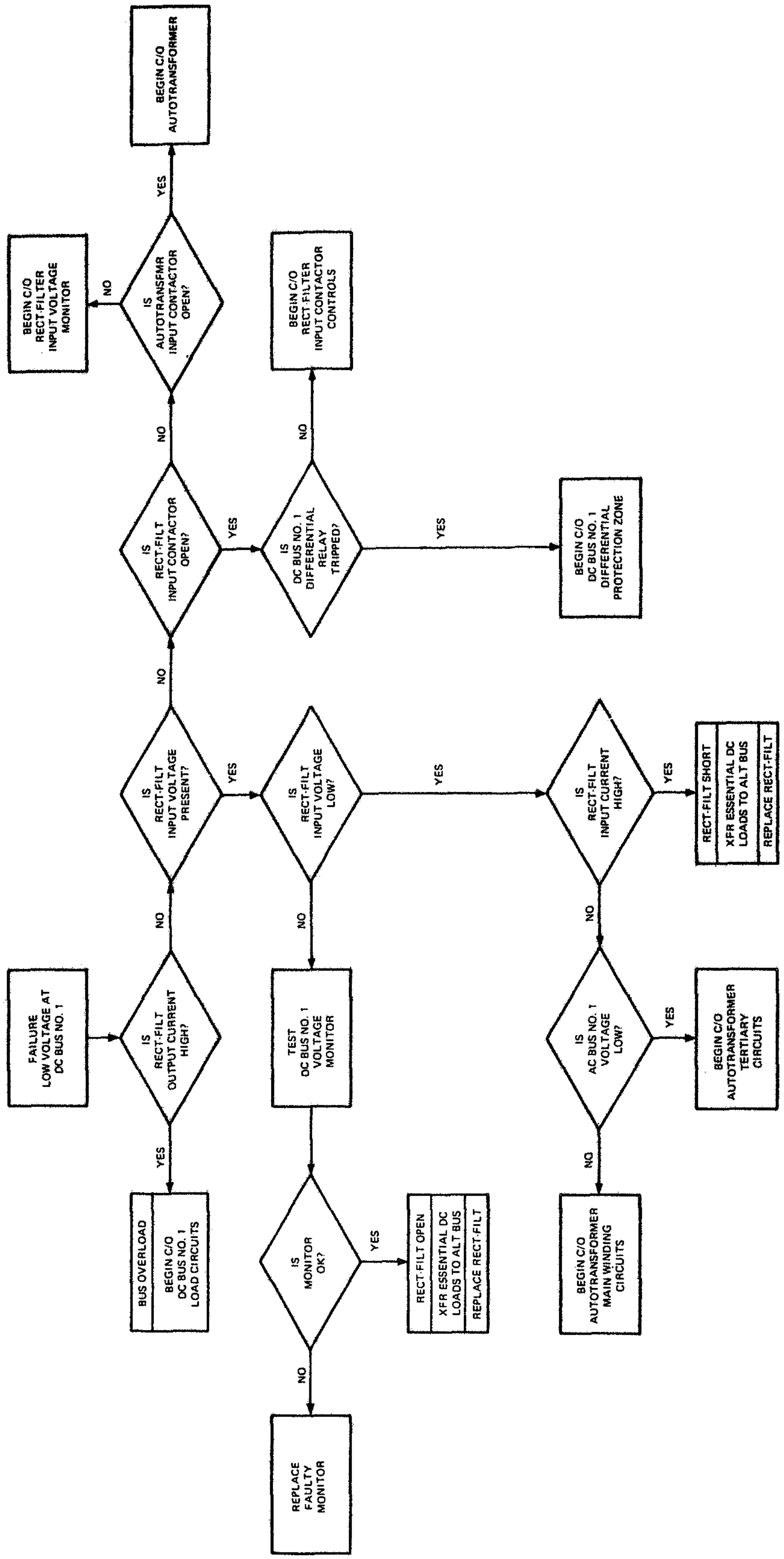


Figure 7-1. Typical Fault Isolation Flow Diagram

The batteries are designed for 100 ampere-hour capacity. Each battery is made up of 25 three-cell modules connected electrically in series for a total of 75 cells per battery. The EPS requires twelve of these batteries. The cells are packaged in three cell modules to facilitate on-orbit maintenance. Each cell has provisions for bypassing a failed cell and for sensing voltage, current, and pressure. In addition, provisions for a load resistor are included for reconditioning the cell.

Operation of the solar arrays and batteries is controlled by the DMS and requires a minimum of crew supervision. Operational parameters are those required for controlling the bi-stem actuator motors and monitoring the extended length of panels. These operations are required only when extending or retracting the solar panels. The solar panels are retracted prior to replacement and are partially retracted prior to operation in the artificial gravity mode. They are deployed initially after orbit is achieved, and then after replacement or at the completion of artificial gravity operations. Initial deployment of the panels is performed automatically since the Space Station is unmanned.

7.6.3.2.1 Status Monitoring

Continuous monitoring of batteries and solar panels is required to determine out-of-tolerance conditions that could lead to failure or reconditioning requirements.

Cell voltages and pressures are sampled at the rate of once per second and cell temperatures at the rate of four times per hour. The temperature and pressure are related functions and do not require the same sampling rates. These parameters are sampled by the DMS computer to indicate the condition of each cell. If a cell is out of programmed tolerance, the cell is bypassed or reconditioned under DMS control. Periodic reconditioning of off-line cells is also required. The cell state-of-charge signal, a small output voltage, is sampled once per second. This value combined with the cell temperature, pressure, and voltage values gives an indication of the state-of-charge of each cell. When predetermined values are reached, the DMS commands the battery charger to reduce the charge rate to a trickle charge rate since the cell is near full charge.

Other battery parameters such as battery voltage and current are sampled once per minute while coolant temperature is monitored at a rate of four times per hour. These parameters are sampled to determine the overall status of each battery.

A battery failure must be indicated to the crew whenever more than three cells have failed. This is accomplished by the DMS generating a caution signal. All other solar array and battery status monitoring is noncritical.

The array blanket temperatures, total panel currents, and panel boom tip deflections are sampled once per minute. Blanket temperatures and panel currents are sampled to determine the overall status of the solar panels. The boom tip deflections are used to determine the solar incidence angle on the array surface and to detect degradation of the optical properties of the panels and the bi-stem booms.

7.6.3.2.2 Periodic Checkout

Periodic checkout of solar arrays and batteries is performed at intervals ranging from once per day to once per month depending upon the equipment or parameters to be checked. These are summarized as follows:

Equipment or Parameter	Checkout Interval
Panel extended length	Once per day
Array circuit voltages	
Array circuit currents	
Battery Controls	Once per week
Battery on-off indications	
Battery cell recondition signals	
Battery cell by-pass control	Once per month
Battery cell by-pass indication	

The periodic tests are required to supplement the continuous status monitoring to make a quantitative evaluation of system operating characteristics and to verify the operation of standby or inactive equipment. The checkout is relatively simple as it includes only readouts of parameters such as voltage and current, and verification of the operability of switches and signals.

7.6.3.2.3 Trend Analysis

Changes in the solar array circuit I-V characteristics with time are necessary to detect degradation trends. Therefore, each separate array circuit is periodically switched off the unregulated bus for the determination of the open-circuit voltage, short circuit current, and the current and voltage at several other intermediate points on the I-V characteristic. This circuit characteristics curve information for each circuit is obtained once per orbit for the first week of the mission, then once per day for one year, and finally once per week for the remainder of the mission. These data are transmitted to the ground to permit the calculation and extrapolation of solar array damage. A system of auxiliary loads is required to determine the intermediate points on the I-V characteristics.

Trend analysis is also necessary for the battery voltages of each of the twelve batteries for detection of degradation trends. Initial voltage characteristics as well as the previous two weeks' data are retained for comparison.

7.6.3.2.4 Fault Isolation

Solar array and battery controls are based on monitoring solar array circuit and battery cell performance. This monitoring is used for detecting cell failures and initiating corrective action. A typical fault isolation flow diagram is shown in Figure 7-2 for a battery failure.

A battery failure occurs when more than three cells in the battery have failed. The switching out of one battery is not critical as the other batteries will take a share of the load. A caution indication is used to show that a battery has failed. A failed battery must be removed from the system to avoid affecting other components and/or causing further battery damage. Therefore, the failed battery must be located and verification made of its isolation. For continued operation the condition of the other batteries must be determined to prevent a severe drain on these batteries. This could require some loads to be rescheduled or reduced.

7.7 INTEGRATED SUBSYSTEM TEST DEFINITION

Changes required in the integrated tests defined for the isotope/Brayton configuration have been identified. One additional integrated test was defined.

7.7.1 DMS/EPS

The DMS has a power management interface with the Electrical Power Subsystem. This function includes:

- Power switching of individual load equipment (power profile management) by means of computer-controlled solid-state circuit breakers (NAR baseline)
- Automatic paralleling and load division control of inverter modules
- Control of battery recharging and cell conditioning on a per-cell basis

Fault isolation is performed by DMS self-checks that verify proper generation and transmission of control functions to the interface.

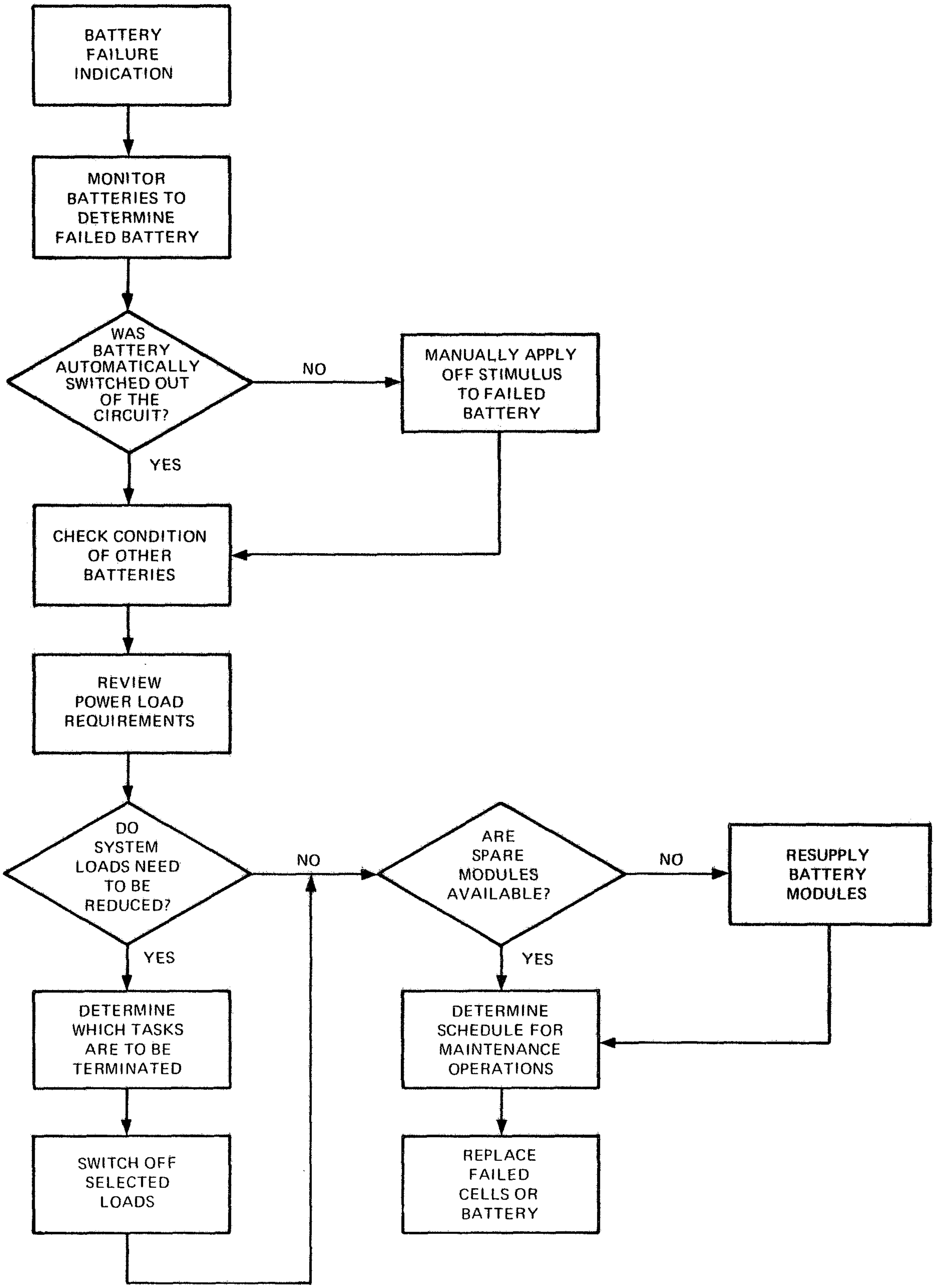


Figure 7-2. Typical Fault Isolation Flow Diagram

Active DMS control is also required for orientation of solar array panels. This function involves a DMS interface with both the Electrical Power and Structures Subsystems. It is assumed that wide angle sun sensors are incorporated as part of the EPS array to determine solar panel position with respect to the sun. The DMS provides the logic required to position the panels during Earth occultation and to reacquire the sun when leaving the shadowed portion of the orbit. Panel orientation then requires DMS control of the X-axis and Y/Z axis drive units in the Structures Subsystem based upon DMS monitoring of turret head and torque shaft positions as well as EPS sun sensor data. For fault localization, the DMS can verify receipt of proper sun and panel position data from the EPS by comparison of data from redundant sensors. The DMS can then check its own capability to operate on and transform the data into appropriate drive unit commands, and verify the transmission of the control data to the Structures Subsystem. Verification of proper response and operation of the Structures Subsystem can be made by monitoring individual drive unit performance.

Section 8

DATA MANAGEMENT SYSTEM PERFORMANCE ANALYSIS

8.1 INTRODUCTION

Based on the checkout requirements derived as a result of Task 1, an analysis of the software requirements to perform checkout of each subsystem was completed in Task 2. Checkout programs were sized by combining the language element usage for each program module and the estimate of DMS requirements for each element.

A measure of the parameters of performance of the DMS was established. These include:

- Flexibility
- Functional Satisfaction
- Speed
- Memory sizing

Based on the software sizing analysis from Task 2, the above parameters were evaluated against the sum of subsystems for which onboard checkout has been considered, and conclusions have been drawn concerning the adequacy of the DMS to perform the checkout task. Finally, an analysis was performed to determine if a role exists for preprocessors in the checkout task.

8.2 ADEQUACY OF THE DMS BASELINE

The DMS adequacy was analyzed with respect to the following considerations:

- Computer execution
- Memory size
- Data bus loading
- Configuration flexibility
- Effect of isotope/Brayton versus solar array
- Checkout philosophy

From these, no inadequacies were found. The hardware specifications are reasonable and obtainable within the current state-of-the-art when space-qualified.

However, certain alternate design approaches should be considered as a result of the checkout analysis. These changes are suggested solely from an OCS point of view and other areas should be investigated before committing to the change. These suggested changes are:

- The process of dedicating memory to a processor (denying other processors access) is undesirable. A failure of the dedicated memory renders the processor unusable at the same time.

- The configuration indicating a bus controller switch matrix and a memory switch matrix is undesirable. It is difficult to isolate to an LRU which is a smaller unit than the switch matrix assembly. If the switch matrix assembly is a single LRU, then the entire DMS is disabled during a remove-and-replace of the matrix.

- For configuration control simplification, it would be desirable to consider the "shared auxiliary" memory and "bulk" memory in the same manner (i.e., a peripheral device accessed via the data bus).

- Interconnection between processor and memory and between processors and data bus controllers should be designed for multiple simultaneous corrections.

8.3 DATA MANAGEMENT SYSTEM PERFORMANCE

Based on the program module sizing information from Task 2 and the measurement and stimulus information derived earlier in Task 1, an estimate of the DMS performance required to execute the OCS task was made. Parameters analyzed include data bus utilization, processor utilization, and main memory required.

8.3.1 DATA BUS UTILIZATION

Based on the Measurement and Stimulus List of Appendix I, an analysis was performed to estimate the data bus rates required to acquire data for the onboard checkout task. Table 8-1a summarizes the data rate for each subsystem, and

Table 8-1a. Subystem Data Rates

Space Station System	Analog		Bilevel		Total
	Meas/ Sec	Bits/ Sec	Meas/ Sec	Bits/ Sec	Bits/ Sec
Guidance, Navigation, and Control	40.31	3,547.28	36.00	288.00	3,835.28
Hi Thrust Propulsion	41.00	3,608.00	12.00	96.00	3,704.00
Lo Thrust Propulsion	94.00	8,272.00	78.00	624.00	8,896.00
EC/LS	340.00	29,920.00	50.00	400.00	30,320.00
Communications	0.96	84.48	0	0	84.48
Structures	7.00	616.00	0	0	616.00
EPS-I/BR	22.07	1,942.16	0	0	1,942.16
EPS(TDC) I/BR Baseline	156.64	13,784.32	37.63	301.04	14,085.36
DMS	1.10	96.80	2.23	17.84	114.64
EC/LS Brayton Cycle	4.00	352.00	0	0	352.00
EC/LS Solar Array	2.00	176.00	6.00	48.00	224.00
Structure Solar Array	0	0	0	0	0
EPS(TCD)-Solar Array	47.44	4,174.72	179.07	1,432.56	5,607.28
EPS-Solar Array/Battery	2,702.40	237,811.20	12.00	96.00	237,907.20

subsystem delta considering the Solar Array and Isotope/Brayton Power Subsystems. In arriving at the data rates, the following assumptions were made concerning the command and data word formats:

• A command will require		44 bits	
• A response will consist of		26 bits	
	plus	18 bits	for each analog word or discrete word or 11 bilevel words
	Total	88	

This results in a worst case of 88 bits per analog or discrete word and 8 bits per bilevel measurement. The worst case was used for the data rates in Tables 8-1a and 8-1b. These bit rates represent an "average" rate and are calculated using status monitoring and trend analysis parameters whose sample rates are one/minute or faster. Sample rates less than one/minute, periodic checkout and calibration tests, and fault isolation tests occur so infrequently that no appreciable effect on the average rate occurs. Periodic checkout and calibration tests are scheduleable so that peaks can be avoided. Although fault isolation tests cannot be scheduled, other activities can be curtailed during periods of fault isolation to avoid peak data rates.

Table 8-1b, presents the same data with the concept of remote limit checking implemented. This concept is described in Section 4, Baseline Subsystem Descriptions. Data in Table 8-1b, is calculated assuming that no data is transmitted unless the data is required for operational or trend analysis purposes.

Assuming a continuous requirement for status monitoring for all subsystems and a scheduleable periodic checkout and fault isolation function, Table 8-2 shows the data rates and utilization rates of the baseline one-megabit subsystem data channel of the Space Station data bus.

As Table 8-2 indicates, a significant reduction in data bus utilization is achieved by the use of remote limit checking in the solar-powered Space Station configuration.

Although there are obvious hardware penalties in implementing this concept in the RDAU, it is believed that this option should be further considered in the Space Station DMS design.

8.3.2 PROCESSOR UTILIZATION

It was assumed that the average load on the processor was approximately represented by the status monitoring and trend analysis functions as the other functions, i.e., periodic checkout, calibration, and fault isolation tests, occur

Table 8-1b. Subsystem Data Rates

Space Station System	Analog		Bilevel		Total
	Meas/ Sec	Bits/ Sec	Meas/ Sec	Bits/ Sec	Bits/ Sec
Guidance, Navigation, and Control	0.24	21.12	0	0	21.12
EC/LS	49.00	4,312.00	0	0	4,312.00
Communications	.002	0.18	0	0	0.18
EPS(TED) I/BR Baseline	60.12	5,290.56	0	0	5,290.56
DMS	0.34	29.92	0	0	29.92
ESP(TED) Solar Array	0.067	5.90	0	0	5.90

Table 8-2. Data Bus Utilization

Space Station Configuration	Average Data Rate		Data Bus Utilization	
	Without Limit Check	With Limit Check	Without Limit Check	With Limit Check
Isotope/Brayton	62,830	9,430	6.28%	.9%
Solar Array	285,500	4,260	28.6%	.4%

infrequently and can be scheduled to avoid peak loads. Therefore, the analysis was directed toward analyzing these functions with respect to processor capability required for their execution.

Table 8-3 shows the execution rates and the number of points to be monitored for status for both the isotope/Brayton and solar array Space Station configurations. Summing the requirements from Table 8-3, results in a total of 3,751,621 data points per hour to be monitored for the isotope/Brayton configuration and 13,581,521 data points per hour to be monitored for the solar array configuration. Based on the utilization formula

$$\rho = E(t_s)$$

where

ρ = utilization

λ = arrival rate

$E(t_s)$ = estimated mean service time

and assuming that for a multiprocessor of three $E(t_s)$ = 200 microseconds, the processor time required to perform limit checking for one station monitoring test point is:

$$\rho I/BR = \frac{1}{3} \times \frac{3,751,621}{3600} \times 200 \times 10^{-6} = .07 \text{ or } 7\%$$

and

$$\rho sa = \frac{1}{3} \times \frac{13,581,521}{3600} \times 200 \times 10^{-6} = .252 \text{ or } 25.2\%$$

Table 8-3. IBR/EA Space Stations Status Monitoring

Subsystem	RATES							
	1/D	1/H	4/H	1/M	2/M	6/M	1/S	5/S
GN&C		24/24		18/18			108/108	
Propulsion							299/299	
EC/LS				8/8			368/380	
RF Communications				58/58				
Structures							7/7	
Electrical Power			37/962	40/96	331/1164	26/74	118/2832	18/12
Data Management	96/96	65/65		141/141			34/34	
Total	96/96	89/89	37/962	265/321	331/1164	26/74	934/3660	18/12

As an additional load, the two most frequently used trend analysis programs sum to an additional duty cycle of .11%.

When the RDAU performs limit checking and interrupts the multiprocessor only when an out-of-limit condition occurs, the only activity remaining is that to assure proper RDAU operation. Assuming wrap and memory tests require 60 + 1172 = 1232 microseconds (Section 6) and are executed once every 20 seconds (worst case) and that RDAU can access 40 test points, the utilizations become

$$\rho I/BR = \frac{1}{3} \times \frac{101}{20} \times 1232 \times 10^{-6} - .0021 \text{ or } .21\%$$

$$\rho SA = \frac{1}{3} \times \frac{236}{20} \times 1232 \times 10^{-6} = .0048 \text{ or } .48\%$$

Based on these assumptions, Table 8-4 summarizes the multiprocessor utilization for each case considered.

Table 8-4. Processor Utilization Summary

Configuration	Centralized Limit Check	Remote Limit Check
Isotope/Brayton	7.1%	0.3%
Sales Array	25.3%	0.5%

It can be seen from Table 8-4 that the incorporation of the remote limit checking capability of the RDAU as described in the Baseline DMS Description results in a significant decrease in the utilization of the multiprocessor for checkout.

8.3.3 MEMORY REQUIREMENTS

Main memory requirements are estimated as the sum of those programs requiring constant residence in main memory and the checkout program currently being executed. The EC/LS trend analysis module is the only program with a sufficiently rapid iteration rate to warrant constant residence in main memory. The largest checkout module is estimated at about 19,000 words. Several are 2,000 to 5,000 words long, but most are smaller. It is estimated therefore, considering overlay capability, that an allocation of 8,000 words is sufficient for the checkout module being executed. The total main memory requirements, therefore, are:

Checkout Executive	64,000 words
Current Program Module	8,000 words
EC/LS Trend Analysis Module	150
	72,150 words

This main memory requirement represents about 28 percent of the 256, 000-word main memory capacity.

The total memory required for all the checkout modules identified in Task 2 is 290, 000 words. These must be stored in auxiliary memory when not in execution. This auxiliary memory requirement represents about 11 percent of the 2.5-million-word auxiliary memory capacity.

8.4 USE OF PREPROCESSORS IN THE CHECKOUT TASK

Considerations which, taken together, could dictate a need for preprocessors in the DMS are:

- Inadequate centralized computer speed capability to handle checkout processing
- Inadequate main memory size for subsystem checkout programs
- Special unique instructions required for a given subsystem and not required for other subsystems
- Time critical simultaneous processing requirements between checkout and other processing requirements
- Access to checkout data not required by centralized processor for other reasons

In the Engineering Study of Onboard Checkout Techniques no requirement to add preprocessors to aid the DMS computer in performance of the centralized Space Station checkout task was identified. Given the addition of preprocessors for operational purposes, they could possibly be used to advantage by the checkout function. This is not a requirement at present, however, and its cost effectiveness needs to be determined.

Some criteria that may be used for a decision are:

- To the extent that checkout uses operational data available most readily to the preprocessors, it may be done by the preprocessors
- To the extent that checkout requires data from other interfacing subsystems, the DMS computer would be preferred
- Mode control, subsystem configuration, and redundancy management should be done in the DMS computer

- Lower level checkout could be done in preprocessors, but integrated checkout should be assigned to the DMS computer.

Special consideration was given to the use of the five GN&C preprocessors in the checkout of the GN&C Subsystem. Since no data was available on the preprocessor memory, cycle time, or other performance characteristics, no decision could be made on the use of these preprocessors. However, some considerations for and against the use of these preprocessors for checkout were derived. These are:

- Splitting the checkout function between the DMS computer and GN&C preprocessors could mean programming the checkout function in two or more different languages.

- If the preprocessors are sized to perform their respective operational loads only, they might be incapable of doing the checkout task, too.

- Current estimates indicate no need for checkout assistance from the preprocessors by the DMS computer.

- Splitting the checkout task between computers will result in some coordination and synchronization problems not found in a centralized concept.

- Assuming the preprocessors have easy access to all checkout data, they could perform checkout as easily as the DMS computer, and in addition, decrease the data bus load.

- Use of preprocessors lets some specialized checkout algorithms be assigned to their respective subsystems and allows more standard DMS software to be developed independently.

- Any checkout function transcending two or more preprocessors incurs the cost of complicated data transfer and synchronization through the data bus and DMS computer.

- Any preprocessor checkout data may also have to be available to the crew via data bus, DMS computer, and display system. Any saving in use of the preprocessor is therefore subject to this added expense.

- Some utility routines may have to be repeated in the preprocessors if checkout is done therein.

The option of delegating some checkout functions to preprocessors, taking the above into consideration, will remain open for some time. A likely solution is to do some in both places. The Optical Reference and CMG preprocessors could do much of their respective subsystems' checkout. The IMU and RCS preprocessors should let the DMS do much of their subsystems' checkout. Since the IMU preprocessor smoothes out changes in vehicle roll rate and velocities and receives hardware status information, it could do some checkout, also.

The Local Level Flight Mode Navigation function could be checked by the preprocessor, but Inertial Flight Mode Navigation, Space Station Attitude Control, Transposition and Docking, and Orbital Maintenance should be done using the DMS computer to a large extent.

It is interesting to note that the "Space Station IMS Trade-off Study Report", Section 6, Onboard Checkout (Enclosure 3 to RFP BG 721-7-0-318 P) considered the subsystem/experiment-oriented preprocessors the least attractive of several checkout control alternatives. Primary reasons for this rating were higher software development costs, additional hardware development and procurement costs, and increased power, weight and volume requirements. The principal advantage was in reduced data bus traffic and reduced processor utilization. Since the largest loads on both the data bus and the DMS processor are due to status monitoring (primarily limit checking) which can be handled by Remote Data Acquisition Units, this study seems to support the conclusions of the IMS trade study in that preprocessors would not be recommended for checkout purposes alone.

APPENDIX I

SPACE STATION ONBOARD CHECKOUT MEASUREMENT & STIMULUS LIST

Table I-1

SUBSYSTEM: GUIDANCE, NAVIGATION, CONTROL	QUANTITY	CATEGORY (S, R)	TYPE (A, B, D, P, R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Star Tracker Gimbal Commands	4	S	A								4	(4) 1MO	1/S	4	1/S	1MO			-1	1/S	(4) Or prior to inertial attitude mode.
Simulated Star Tracker Dissector Outputs	4	S	A								4	(4) 1MO							4		
STAR TRACKER ELECTRONICS ASSEMBLY																					
Star Tracker Operating Mode Commands	2	S	D								2	(4) 1MO							2		
LANDMARK TRACKER											1										
Landmark Tracker Encoder Outputs	2	R	D								2	(5) 1W	10/S	2	1/S	1MO			2	10/S	(5) First year only, then 1 MO interval .
Landmark Tracker Gimbal Commands	2	S	A								2	(5) 1W	10/S	2	1/S	1MO			2	10/S	
Landmark Tracker Detector Outputs	2	R	A								2	(5) 1W	10/S						2	10/S	
Simulated Landmark Tracker Detector Outputs	2	S	A								2	(5) 1W	10/S						2	10/S	
LANDMARK TRACKER ELECTRONICS ASSEMBLY																					
Landmark Tracker Operating Mode Commands	2	S	D								2	(5) 1W							2		
ACCELEROMETER																					
Accelerometer Temperature	2	R	A				1/M	2									2	(2) 1/M	2		
ACCELEROMETER ELECTRONICS																					
Accelerometer Rebalance Signals (Outputs)	3	R	A								3	1MO	1/S						3	1/S	Checks overall accelerometer gain Compare with navigation data.
Accelerometer Heater Voltage	2	R	A														2	(3) 1/M	2		
Accelerometer Operating Mode Commands	2	S	B								2	1MO							2		
Simulated Accelerometer Outputs	3	R	B								3	1MO							3		
RENDEZVOUS TRACKER HEAD																					Compare with other tracker & navigation data.
Rendezvous Tracker Outputs	4	R	D								4	(6)	1/S						4	1/S	(6) Event oriented to rendezvous or FFM station keeping. ~ 1 week.
Tracker Transmitter Power Monitor	4	R	A								4	(6)					4	(7)	4		
Tracker Receiver Energy Monitor	4	R	A								4	(6)					4	(7)	4		(7) Average of 10 samples/operation; fault isolation against values saved.
RENDEZVOUS TRACKER GIMBAL ASSEMBLY																					
Gimbal Torquer Commands	8	S	A								8	(6)		8		(6)			8		
Tracker Gimbal Angles	8	8	D								8	(6)		8		(6)			8		
RENDEZVOUS TRACKER ELECTRONICS																					
Tracker Electronics Stimuli	4	S	D																4		Used to isolate fault between head and electronics.

Q-Quantity
S-Stimulus
R-Response

A-Analog
B-Bilevel
D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
W-Week
MO-Month

Table I-1

SUBSYSTEM: GUIDANCE, NAVIGATION, CONTROL — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Tracker Operating Mode Commands	4	S	D								4	(6)							4		
DOCKING TRACKER																					
Docking Tracker Outputs	7	R	D								7	(8)	1/S						7	1/S	(8)Prior to docking events or ~ 1MO.
Docking Tracker Xmtr Power Monitor	7	R	A								7	(8)					7	(7)	7		
Docking Tracker RCVR Energy Monitor	7	R	A								7	(8)					7	(7)	7		
DOCKING TRACKER ELECTRONICS																					
Docking Tracker Electronics Stimuli	7	S	D								7	(8)							7		
Docking Tracker Operating Mode Commands	7	S	D								7	(8)							7		
SENSOR ALIGNMENT MONITOR XMTR																					
Sensor Alignment Monitor Xmtr Outputs	4	R	A								4	(9) 1MO							4		Compare against alignment matrix.
Alignment Xmtr Detector Outputs	2	R	A								2	(9) 1MO							2		(9)Or after docking event.
Alignment Xmtr Light Source Monitors	4	R	B																4		
Alignment Xmtr Motor Speed Monitors	4	R	A								4	(9) 1MO							4		
Alignment Monitor Operating Mode Command	2	S	B								2	(9) 1MO							2		
SENSOR ALIGNMENT MONITOR RCVR																					
Alignment RCVR Output	2	R	A								2	(9) 1MO							2		Compare against alignment matrix.
EXPERIMENT ALIGNMENT MONITOR RCVR																					
Experiment Alignment Monitor RCVR Outputs	18	R	B								18	(9) 1MO							18		Compare against alignment matrix.
Experiment Alignment Monitor Mode Command	2	S	B								2	(9) 1MO							2		
Experiment Alignment RCVR Detector Outputs	6	R	A								6	(9) 1MO							6		Compare against alignment matrix.
EXPERIMENT ALIGNMENT MONITOR XMTR																					
Experiment Alignment Monitor Source Power	2	R	B																2		
INTERFACE ELECTRONICS MODULE																					
Interface Buffer Outputs	24	R	D				1/S	24			24	1MO	10/S						24	10/S	Compare with operational data. (applies to Interface Buffer Outputs, Control and Address)
Interface Buffer Control	12	S	D								12	1MO	10/S						12	10/S	
Interface Buffer Address	12	S	D								12	1MO	10/S						12	10/S	
Interface Buffer Reset	12	S	D								12	1MO	10/S						12	10/S	

Q-Quantity, S-Stimulus, R-Response
A-Analog, B-Bilevel, D-Digital
P-Pulse, R-RF, SI-Sampling Interval, SR-Sampling Rate
S-Second, M-Minute, H-Hour, D-Day, W-Week, MO-Month

Table I-1

SUBSYSTEM: GUIDANCE, NAVIGATION, CONTROL	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
HIGH THRUST JET DRIVER MODULE																					Indicates electronics quant. to fire. Compare with DMS Operational Command Data
Jet Driver Inputs	36	S	B								36	1W	1/S				36	(10)	36		(10) Trend jet analysis data is to count number of jet firing events over time period of 1 day.
Jet Driver Reset	36	S	B								36	1W	1/S						36		Reset driver if it fired when not commanded to do so.
Jet Control Operating Mode Commands	4	S	B								4	1W							4		Sequence each amplituder twice.
Jet Driver Outputs	36	R	B				1/S	36			36	1W	1/S						36	1/S	
BACKUP CONTROL ELECTRONICS MODULE																					
Backup Control Electronics Inputs	6	R	D								6	1W							6		Indicates sensor outputs.
Backup Control Electronics Outputs	20	R	B								20	1W							20		
RESISTOJET CONTROL ELECTRONICS MODULE																					
RESISTOJET DRIVER INPUTS	32	S	B								32	1W							32		
RESISTOJET DRIVER OUTPUTS	32	R	B				1/S	32			32	1W							32		
CMG ROTOR/GIMBAL ASSEMBLY																					
CMG SPIN RATE MONITOR	4	R	A				1/H	4											4		
CMG SPIN POWER MONITOR	4	R	A														4	1/H	4		
CMG VIBRATION MONITOR	8	R	A				1/H		8								8	1/H	8		Each sample consists of 5 seconds of data
CMG BEARING TEMPERATURE MONITOR	8	R	A				1/H		8								8	1/H	8		
CMG VACUUM MONITOR	4	R	A				1/H	4									4	1/H	4		
CMG TORQUER/ENCODER ASSEMBLY																					
CMG Gimbal Encoder Output	8	R	D				1/S	8			8	1MO	1/S	8	1/S	1MO			8	1/S	Related to CMG torquer command.
CMG Torquer Current	8	R	A								8	1MO	1/S	8	1/S	1MO			8	1/S	Check against Torquer Commands
CMG Gimbal Rates	8	R	A				1/S	8			8	1MO	1/S	8	1/S	1MO			8	1/S	
CMG ROTOR CONTROL MODULE																					
CMG Speed Control Signals	4	R	A																4		To isolate between CMG and electronics.
CMG TORQUER CONTROL MODULE																					
CMG Operating Mode Commands	8	S	B								8	1MO							8		
CMG Torquer Commands	8	R	A								8	1MO	1/S						8	1/S	
GYRO AND ACCELEROMETER MOUNT ASSEMBLY																					

Q-Quantity
S-Stimulus
R-Response

A-Analog
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P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
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Table I-1

SUBSYSTEM: GUIDANCE, NAVIGATION, CONTROL	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
HORIZON SENSOR MOUNT ASSEMBLY																					
None																					
STAR TRACKER/STAR SENSOR MOUNT ASSEMBLY																					
Calibration Light Source Monitor	2	R	B											2		1MO			2		
LANDMARK TRACKER MOUNT ASSEMBLY																					
Calibration Target Monitor	2	R	B											2		1MO			2		

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R-RF
SI-Sampling Interval
SR-Sampling Rate

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D-Day
W-Week
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Table I-2

SUBSYSTEM: HI THRUST PROPULSION — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
PRESS STORAGE ASSEMBLY																					(1)Quantity column reflects art-6-period (1st 2 yrs)/zero-6 period (yrs 2-10)
Press (0 - 4200 psia)	(1) 4/2	R	A				1/S			4/2	4/2	1/D	1/S	4/2		3MO	4/2	1/D	4/2	1/S	(2)Trending for usage crate of changes and quantity determination
Temp (0-200°F)	4/2	R	A								4/2	1/D		4/2		3MO	4/2	1/D	4/2		(3)Reflect dedicated controls necessary for manual operation
Valve Position	4/2	R	B								4/2	1/D							4/2		
Valve Control	4/2	S	B	(3) 4/2							4/2	3MO							4/2		
Relief Valve Actuation	4/2	R	B				1/S	4/2			4/2	1/D	1/S						4/2	1/S	
HI-PRESS-MANIFOLD																					
Press (0 - 4200 psia)	2	R	A				1/S			2	2	1/D	1/S	2		3MO	2	1/D	2	1/S	
Valve Position	3	R	B								3	1/D							3		
Valve Control	3	S	B	(3) 3							3	3MO							3		
PRESS CONTROL ASSEMBLY																					
Press Switch	4	R	B								4	3MO		4		3MO			4		
Valve Position	2	R	B				1/S		2		2	1/S	1/S						2	1/S	
Valve Control	2	S	B	(3) 2							2	3MO							2		
LO-PRESS MANIFOLD																					
Press (0 - 400 Psia)	2	R	A				1/S		2		2	1/D	1/S	2		3MO	2	1/D	2	1/S	
Valve Position	3	R	B								3	1/D							3		
Valve Control	3	S	B	(3) 3							3	3MO							3		
PROPELLANT STORAGE ASSEMBLY																					
Press (0 - 400 psia)	142	R	A				1/S		14/2		14/2	1/D	1/S	14/2		3MO	14/2	1/D	14/2	1/S	
Temp (0 - 200 F)	142	R	A								14/2	1/D		14/2		3MO	14/2	1/D	14/2		
Valve Position	28/4	R	B								28/4	1/D							28/4		
Valve Control	28/4	S	B	28/4							28/4	3MO							28/4		
Relief Valve Actuation	14/2	R	B				1/S	14/2			14/2	1/D	1/S						14/2	1/S	
Quantity Guaging Assembly	14/2	R	A								14/2	1/D		14/2		3MO	14/2	1/D	14/2		
PROPELLANT MANIFORD																					
Press (0 - 400 psia)	3	R	A				1/S		3		3	1/D	1/S	3		3MO	3	1/D	3	1/S	

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R-RF
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SR-Sampling Rate

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M-Minute
H-Hour
D-Day
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Table I-2

SUBSYSTEM: HI THRUST PROPULSION (Con't)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING	Non Crit	Cau tion	Warn ing	PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Valve Position	9	R	B								9	1/D							9		
Valve Control	9	S	B	(3) 9							9	3MO							9		
THRUSTOR MODULES																					
Press (0-400 psia)	20/ 10	R	A				1/S		4/2		20/ 10	1/D	1/S	20/ 10		3MO	20/ 10	1/D	20/ 10		
Press Chamber (0-600 psia)	36/ 12	R	A				(4)	14/6			36/ 12	3MO 1/D	250/	36/ 12		3MO			36/ 12		Indicates that thrustor opened; record pressure vs time trace (~ soms/thrustor) every 3 MO.
Temp Head (0-1000°F)	36/ 12	R	A				(4) 1/S	14/6			36/ 12	1/D		36/ 12		3MO	36/ 12	1/D	36/ 12		(4)Required only during thrustor operation
Valve Position	20/ 10	R	B								20/ 10	1/D							20/ 10		
Valve Control (ISO)	20/ 10	S	B								20/ 10	3MO							20/ 10		
Valve Control (Thrustors)	36/ 12	S	B	(3) 36/12							36/ 12	3MO							36/ 12		
Voltage (Bus)	4/2	R	A				1/S	4/2			4/2	1/D	1/S						4/2		
PURGE ASSEMBLY																					
Press (0-4200 psia)	2	R	A				1/S			2	2	1/D	1/S	2		3MO	2	1/D	2		
Press (0-400 psia)	2	R	A				1/S		2		2	1/D	1/S	2		3MO	2	1/D	2		
Valve Position	8	R	B								8	3MO							8		
Valve Control	8	S	B								8	3MO							8		
Reg Control	1	S	B								1	3MO							1		
Relief Actuation	2	R	B				1/S	2			1	1/D	1/S						2		
MISCELLANEOUS									1												
Temp Measurements	100/ 50	R	A								100/ 50	1/W		100/ 50		6MO			100/ 50		
RESUPPLY ASSEMBLY (STATION)																					
Press (0-400 & 0-4200 psia)	2	R	A				1/S			2	2	1/D	1/S	2		3MO			2		
Valve Position	4	R	B								4	1/D							4		
Valve Control	4	S	B	(5) 4							4	3MO							4		(5)Required only during resupply operation
CARGO MODULE RESUPPLY SUBSYSTEM																					
Hi Press Assembly																					
Press (0-4200 psia)	4/2	R	A				1/S			4/2	4/2	3MO	1/S								Required only with cargo module docked.
Temp (0-200°F)	4/2	R	A				1/S	4/2			4/2	3MO	1/S								

Q-Quantity, S-Stimulus, R-Response
A-Analog, B-Bilevel, D-Digital
P-Pulse, R-RF, SI-Sampling Interval, SR-Sampling Rate
S-Second, M-Minute, H-Hour, D-Day, W-Week, MO-Month

Table I-2

SUBSYSTEM: HI THRUST PROPULSION	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
Measurement/stimulus signal				Q	SI	SR	SR	Non Crit Q	Caution Q	Warning Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Valve Position	2	R	B								2	3MO									
Valve Control	2	S	B	2							2	3MO									
Relief Actuation	4/2	R	B				1/S	4/2			4/2	3MO	1/S								Required only with cargo module docked.
LO PRESSURE ASSEMBLY																					
Press (0-400 psia)	4/2	R	A				1/S		6/2		4/2	3MO	1/S								
Temp (0-200°F)	14/2	R	A				1/S	14/2			14/2	3MO	1/S								
Valve Position	4/2	R	B								4/2	3MO									
Valve Control	4/2	S	B	6/2							4/2	3MO									
Relief Actuation	4/2	R	B				1/S	6/2			4/2	3MO	1/S								

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S-Stimulus
R-Response

A-Analog
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D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
W-Week
MO-Month

Table I-3

SUBSYSTEM: LOW THRUST PROPULSION — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
COLLECTION/STORAGE ASSEMBLY																					(1)Can schedule all periodic checks when system is down.
Compression Pump Flow	8	R	A				1/S	8			8	1/D	1/S				8	1/D	8		
Compression Pump On/Off	4	S	B								4	3MO							4		Controlled by EC/LS.
Tank Isolation Valve Position	4	R	B								4	1/D							4		
Tank Isolation Valve Control	4	S	B								4	3MO							4		
Prop Control Valve Position	4	R	B				1/S	4			4	1/D	1/S						4		
Prop Control Valve Control	4	S	B								4	3MO							4		
Low Press Mix Valve Position	2	R	B								2	1/D							2		
Low Press Mix Valve Control	2	S	B								2	3MO							2		
High Press Mix Valve Position	2	R	B								2	1/D							2		
High Press Mix Valve Control	2	S	B								2	3MO							2		
Relief Assembly	4	R	B				1/S	4			4	1/D	1/S						4		Should be closed unless pressure is too high.
Storage Bottle Press	4	R	A				1/S		4		4	1/D	1/S	4		6MO	4	1/D	4		Trend is for quantity indication.
Storage Bottle Temp	4	R	A								4	1/D		4		6MO	4	1/D	4		
Low Press Manifold Press	4	R	A								1	1/D		4		6MO			4		Calibration constant update by DMS.
High Press Manifold Press	4	R	A								1	1/D		4		6MO			4		
Low Press Manifold Temp	4	R	A								1	1/D		4		6MO			4		
High Press Manifold Temp	4	R	A								1	1/D		4		6MO			4		
WATER SUPPLEMENT ASSEMBLY																					
Fill/Drain Valve Position	1	R	B								1	1/D							1		
Fill/Drain Valve Control	1	S	B								1	3MO							1		
Tank Isolation Valve Position	2	R	B								2	1/D							2		
Tank Isolation Valve Control	2	S	B								2	3MO							2		
Flow Control Valve Position	2	R	B								2	1/D							2		
Flow Control Valve Control	2	S	B								2	3MO							2		Controlled by DMS.
Press Inlet Valve Position	2	R	B								2	1/D							2		
Press Inlet Valve Control	2	S	B								2	3MO							2		

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Table I-3

SUBSYSTEM: LOW THRUST PROPULSION — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Pressure Outlet Valve Position	2	R	B								2	1/D							2		
Pressure Outlet Valve Control	2	S	B								2	3MO							2		
H_2O Vaporizer Operation	2	S	B								2	1/D							2		
H_2O Vaporizer Outlet Temp	2	R	A				1/S	2			2	1/D	1/S	2		6MO			2		DMS shuts off assy if temp too high.
H_2O Storage Bottle Press	2	R	A				1/S		2		2	1/D	1/S	2		6MO			2		Calibration constant update by DMS.
H_2O Storage Bottle Temp	2	R	A								2	1/D		2		6MO			2		
Tank Outlet Press	2	R	A								2	1/D		2		6MO			2		
Thermal Control Assembly Control	2	S	B								2	1/D							2		
FLOW CONTROL ASSEMBLY																					
Regulator ISO Valve Position	6	R	B				1/S	6			6	1/D	1/S						6		Two each for H_2O, CH_4, CO_2.
Regulator ISO Valve Control	6	S	B								6	3MO							6		
Cross Feed Valve Position	5	R	B								5	1/D							5		H_2O vapor, high and low CH_4, CO_2 pressure.
Cross Feed Valve Control	5	S	B								5	3MO							5		
Cross Feed Pressure	10	R	A								10	1/D		10		6MO			10		Each side.
Regulator Inlet Press	2	R	A								2	1/D		2		6MO			2		Calibration constant update by DMS } H_2O only
Regulator Inlet Temp	2	R	A								2	1/D		2		6MO			2		
Regulator Outlet Press	6	R	A				1/S		6		6	1/D	1/S	6		6MO			6		Each reg.
THRUSTOR ASSEMBLY																					Expect frequency of periodic thrustor replacement to be > 2 years.
Module ISO Valve Position	24	R	B								24	1/D							24		
Module ISO Valve Control	24	S	S								24	3MO							24		
Thrustor Valve Position	32	S	R				1/S	32			32		1/S						32		
Thrustor Valve Control	32	S	B								32	3MO							32		
Thrustor Heater Operation	32	R	B				1/S	32			32		1/S						32		
Module Manifold Press	8	R	A				1/S		8		8	1/D	1/S	6		6MO			8		Calibration constant update by DMS.
Heater Resistance	32	R	A				1/S	32			32		1/S						32		
POWER DISTRIBUTION AND CONTROL ASSY																					
Thrustor Control	32	S	B								32	3MO							32		
Flow Valve Control	6	S	B								6	3MO							6		
Output Voltage	32	R	A				1/S	32			32		1/S						32		

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Table I-4

SUBSYSTEM: EC/LS — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
ATMOSPHERE SUPPLY & CONTROL																					
O_2 GAS STORAGE																					
Tank Pressure	4	R	A	4			1/S			4	4	3MO					4	1/H	4		Measure tank quantity (high limit)
Tank Temperature	4	R	A	4			1/S	4			4	3MO					4	1/H	4		
Shutoff Valve Control	4	S	B	4							4	3MO							4		
Shutoff Valve Position	4	R	B								4	3MO							4		(On-Off)
Diverter Valve Control	4	S	B	4							4	3MO							4		
Diverter Valve Position	4	R	B								4	3MO							4		(Direction)
N_2 GAS STORAGE																					
Tank Pressure	8	R	A	8			1/S			8	8	3MO					8	1/H	8		Measure tank quantity.
Tank Temperature	8	R	A	8			1/S	8			8	3MO					8	1/H	8		
Shutoff Valve Control	8	S	B	8							8	3MO							8		
Shutoff Valve Position	8	R	B								8	3MO							8		
Diverter Valve Control	8	S	B	8							8	3MO							8		
Diverter Valve Position	8	R	B								8	3MO							8		
PRESSURE REDUCTION																					
Upstream Pressure	4	R	A	4			1/S	4			4	3MO							4		Indicates availability of atmospheric supply.
Shutoff Valve Control	4	S	B	4							4	3MO							4		
Shutoff Valve Position	4	R	B								4	3MO							4		
Heater Power Control	4	S	B								4	3MO							4		
Heater On Indication	4	R	P								4	3MO							4		
Heater Temperature	4	R	A								4	3MO							4		
Downstream Pressure	4	R	A				1/S	4			4	3MO							4		
Diverter Vlv Cont., Emerg O_2	4	S	B	4							4	3MO							4		
Diverter Vlv Pos., Emerg O_2	4	R	B								4	3MO							4		

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Table I-4

SUBSYSTEM: EC/LS Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
PRESSURE CONTROL																					
Normal O_2 Supply Pressure	2	R	A	2			1/S		2		2	3MO							2		
Solenoid Valve Control	4	S	B								4	3MO							4		
Solenoid Valve Actuation	4	R	B								4	3MO					4	1/M	4		Measures amount of O_2 and N_2 used (count actuation pulses-for materials check).
Cabin Pressure	2	R	A				1/S		2		2	3MO							2		
Cabin Pressure Control	2	S	B								2	3MO							2		
DUMP AND RELIEF VALVE PRESSURE	4	R	A				1/S	4			4	3MO							4		Leakage check.
DUMP AND RELIEF VALVE POSITION	4	R	B				1/S			4	4	3MO							4		Warning of atmosphere dump.
PUMP DOWN ACCUMULATOR																					
Pressure	3	R	A	3			1/S	3			3	3MO							3		Measures accumulator quantity.
Temperature	3	R	A	3			1/S	3			3	3MO							3		
Shutoff Valve Control	3	S	B	3							3	3MO							3		
Shutoff Valve Position	3	R	B								3	3MO							3		
DOCKING PORT PUMPDOWN PRESSURE	14	R	A	14							14	3MO							14		Needed for pumpdown repressurization operation.
AIRLOCK PUMPDOWN FLOW	10	R	A								10	3MO	1/S						10	1/S	
AIRLOCK PUMP																					
Solenoid Valve Control	4	S	B	4							4	3MO							4		
Solenoid Valve Position	4	R	B								4	3MO							4		
Repressurization Line Press.	1	R	A	1							1	3MO							1		Indicates availability of repressurization air.
Reciprocating Compressor Control	3	S	B	3							3	3MO							3		
Reciprocating Compressor on IND.	3	R	B	3							3	3MO							3		
ATMOSPHERE RECONDITIONING																					
Temperature & Humidity Control																					
Air Inlet Temp.	4	R	A	4							4	3MO							4		
Air Inlet Humidity	4	R	A				1/S	4			4	3MO							4		
Air Inlet CO_2 Concentration	2	R	A				1/S			2	2	3MO							2		
Fan Operation	2	R	B								2	3MO							2		

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Table I-4

SUBSYSTEM: EC/LS (Cont'd)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
Measurement/stimulus signal								Non Crit	Caution	Warning											
				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Fan Performance	2	R	A				1/S	2			2	3MO							2		Pressure Rise
Temperature Sensor Signal	8	R	A								8	3MO							8		
Temperature Control	2	S	A								2	3MO							2		
Temperature Control Response	2	R	A								2	3MO							2		
Circulating Water Inlet Temp	2	R	A								2	3MO							2		
Circulating Water Flow	2	R	A								2	3MO	1/S						2	1/S	
Water Pump Performance	2	R	A								2	3MO							2		
Water Pump on Indication	2	R	B								2	3MO							2		
Condenser Air Outlet Temp	2	R	A								2	3MO							2		
Condenser Outlet Moisture	2	R	B				1/S	2			2	3MO							2		Detects free moisture going to cabin.
Air Mix Temperature	2	R	A								2	3MO							2		
Duct Temperature	6	R	B								6	3MO							6		
Reheater on Indication	6	R	B								6	3MO							6		
Reheater Operation	6	S	B								6	3MO							6		
TRACE CONTAMINANT CONTROL																					
Fan Performance	2	R	A								2	3MO							2		
Fan on Indication	2	R	B								2	3MO							2		
Red Temperature	2	R	A				1/S		2		2	3MO							2		
Heater Control	2	S	B								2	3MO							2		
Heater Control Performance	2	R	A								2	3MO							2		
Diverter Valve Position	2	R	B								2	3MO							2		
Heater Performance	2	R	A								2	3MO							2		
CO_2 CONTROL																					
Air Inlet Humidity	2	R	A								2	3MO							2		
Air Flow Rate	2	R	A				1/S	2			2	3MO							2		
Fan Performance	2	R	A								2	3MO							2		
Fan on Indication	2	R	B								2	3MO							2		

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Table I-4

SUBSYSTEM: EC/LS (Cont'd) Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Diverter Valve Position	18	R	B								18	3MO							18		
Module Sieve Pressure	2	R	A								2	3MO							2		
Silica Gel Downstream Humidity	2	R	A				1/S	2			2	3MO					2	1/H	2		Trend analysis - take same time in cycle.
Silica Gel Downstream Temp	2	R	A								2	3MO							2		
Dumpline Pressure	2	R	A								2	3MO							2		
Vacuum Pump Performance	2	R	A								2	3MO							2		
Vacuum Pump on Indication	2	R	B								2	3MO							2		
CO_2 Accumulator Pressure	2	R	A				1/S	2			2	3MO							2		
Cold Circulating Pump Temp	2	R	A								2	3MO							2		
Cold Circulating Fluid Flow	2	R	A								2	3MO	1/S						2	1/S	
CO_2 Control	2	S	A								2	3MO							2		
CO_2 Controller Performance	2	R	B								2	3MO							2		
CO_2 Conversion																					
CO_2 Flow	2	R	A				1/S	2			2	3MO							2		
Cooling Air Flow	2	R	A				1/S	2			2	3MO	1/S						2	1/S	Disruption of flow will cause overheating.
Reactor Pressure	2	R	A				1/S	2			2	3MO							2		
Reactor Heater on Indication	2	R	B								2	3MO							2		
Controller Control	2	S	B								2	3MO							2		
Reactor Temperature	2	R	A				1/S		2		2	3MO							2		
Controller Performance	2	R	B								2	3MO							2		
Temp Control Valve Position	2	R	A								2	3MO							2		
Cold Circulating Fluid Temp	2	R	A								2	3MO							2		
Cold Circulating Fluid Flow	2	R	A								2	3MO	1/S						2	1/S	
Water Separator Moisture	2	R	B				1/S	2			2	3MO							2		
Condensate Pump Performance	2	R	A								2	3MO							2		
Condensate Pump on Indication	2	R	B								2	3MO							2		

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Table I-4

SUBSYSTEM: EC/LS (Cont'd)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Condensate Flow	2	R	A				1/S	2			2	3MO	1/S				2	1/H	2	1/S	Trend needed for mass balance and possibly for B&D degradation.
WATER ELECTROLYSIS																					
Inlet Water Flow	2	R	A								2	3MO	1/S				2	1/H	2	1/S	
Pump on Indication	2	R	B								2	3MO							2		
Circulating Pump on Indication	2	R	B								2	3MO							2		
Electrolysis Stack Current	24	R	B								24	3MO					24	1/H	24		Indication of failed cells.
Gas-Liquid-Solid Separator Moisture	2	R	B				1/S	2			2	3MO							2		
Water Fluid Pressure	2	R	A								2	3MO							2		
H_2 Outlet Pressure	2	R	A				1/S		2		2	3MO							2		
H_2 Outlet Moisture	2	R	B				1/S	2			2	3MO							2		
O_2 Outlet Flow Rate	2	R	A				1/S	2			2	3MO					2	1/H	2		Needed for vehicle mass balance.
O_2 Outlet Pressure	2	R	A				1/S		2		2	3MO							2		
O_2 Outlet Moisture	2	R	B				1/S	2			2	3MO							2		
Cooling Fluid Inlet Temp.	4	R	A								4	3MO							4		
Cooling Fluid Inlet Flow	4	R	A								4	3MO	1/S						4	1/S	
Control Voltage	2	R	A								2	3MO							2		
Control Current	2	R	A								2	3MO							2		
Control Stimulus	2	S	A								2	3MO							2		
VENTILATION																					
Fan Performance	6	R	A								6	3MO							6		
Fan on Indication	6	R	B								6	3MO							6		
BIOSCIENCE LAB ATMOSPHERE PURIFICATION																					
Primary Fan Performance	1	R	A								1	3MO							1		
Primary Fan on Indication	1	R	B								1	3MO							1		
Secondary Fan Performance	1	R	A								1	3MO							1		
Secondary Fan on Indication	1	R	B								1	3MO							1		

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Table I-4

SUBSYSTEM: EC/LS (Cont'd) — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Bed Temperature	1	R	A				1/S	1			1	3MO							1		Only when unit in operation.
Valve Position	1	R	B								1	3MO							1		
Valve on Indication	1	R	B								1	3MO							1		
Heater on Indication	1	R	B								1	3MO							1		
Heater Controller Actuation	1	S	B								1	3MO							1		
DISPENSARY ATMOS. PURIFICATION																					
Fan Performance	1	R	A								1	3MO							1		
Fan on Indication	1	R	B								1	3MO							1		
TRACE CONTAMINANT MONITORING	7	R	A				1/S		7		7	3MO					7	1/M	7		
WATER MANAGEMENT																					
URINE WATER RECOVERY																					
Chemical Storage Tank Quantity	4	R	A				1/M	4			4	3MO					4	1/D	4		Measures pretreatment chemical quantity.
Chemical Injector on Indicator	4	R	B								4	3MO							4		
Chemical Flow	2	R	A								2	3MO	1/S						2	1/S	Measures expendable useage.
Urine Holding Tank Quantity	4	R	A								4	3MO					4	1/H	4		Needed for mass balance.
Stored Urine PH	4	R	A				1/M	4			4	3MO							4		
Solenoid Valve Position	6	R	B								6	3MO							6		
4-way Valve Position	2	R	B								2	3MO							2		
3-way Valve Position	6	R	B								6	3MO							6		
Urine Feed Flow	2	R	A								2	3MO	1/S				2	1/H	2	1/S	Needed for mass balance.
Evaporator Inlet Temperature	2	R	A								2	3MO							2		
Evaporator Outlet Temp	2	R	A								2	3MO					2	1/H	2		
Fan Performance	2	R	A								2	3MO							2		
Fan Control	2	R	B								2	3MO							2		
Condenser Outlet Temp	2	R	A								2	3MO							2		
Condenser Outlet Moisture	2	R	B				1/S	2			2	3MO							2		
Cooling Fluid Inlet Temp	2	R	A								2	3MO							2		

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Table I-4

SUBSYSTEM: EC/LS (Cont'd) — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Evaporator Outlet Moisture	2	R	A				1/S	2			2	3MO							2		
Pump Performance	2	R	B								2	3MO							2		
Pump on Indication	2	R	B								2	3MO							2		
Water Conductivity	2	R	A	2			1/S	2			2	3MO					2	1/M	2		Major measurement on water condition.
Bacteria Filter Condition	6	R	A								6	3MO					6	1/M	6		Shows degraded condition.
3-way Valve Control	2	S	B								2	3MO							2		
Controller Response	2	R	A								2	3MO							2		
Controller Stimulus	2	S	B								2	3MO							2		
Reclaimed Water Flow Rate	2	R	A				1/S	2			2	3MO	1/S				2	1/H	2	1/S	Needed for mass balance.
WASH & CONDENSATE RECOVERY																					
Holding Tank Quantity	2	R	A				1/S	2			2	3MO					2	1/H	2		
Controller Output	2	S	B								2	3MO							2		
Sensor Output	2	R	A								2	3MO							2		
Pump Performance	2	R	A								2	3MO							2		
Pump on Indication	2	R	B								2	3MO							2		
Pressure Switch Output	2	R	B								2	3MO							2		
R.O. Cartridge Pressure Rise	2	R	A				1/S	2			2	3MO					2	1/H	2		High pressure rise shows degraded cartridge.
Circulating Pump Performance	2	R	A								2	3MO							2		
Circulating Pump on Indication	2	R	B								2	3MO							2		
Circulating Water Flow Rate	2	R	A								2	3MO							2		
Solids Amount	2	R	A				1/S	2			2	3MO					2	1/H	2		
Solids Sensor Control	2	S	A								2	3MO							2		
3-way Valve Position	4	R	B								4	3MO							4		
Conductivity Sensor Output	2	R	A				1/S	2			2	3MO					2	1/H	2		Main indication of water quality.
Conductivity Sensor Control	2	S	A								2	3MO							2		
Bacteria Filter Performance	6	R	B								6	3MO					6	1/H	6		
Recovered Water Flow Rate	2	R	A				1/S	2			2	3MO					2	1/H	2		Needed for mass balance.

Q-Quantity A-Analog P-Pulse S-Second
S-Stimulus B-Bilevel R-RF M-Minute
R-Response D-Digital SI-Sampling Interval H-Hour
SR-Sampling Rate D-Day
W-Week
MO-Month

Table I-4

SUBSYSTEM: EC/LS (Cont'd) Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
WATER STORAGE																					
Potable Water Outlet Temp.	4	R	A								4	3MO							4		
Cooling Water Inlet Temp.	2	R	A								2	3MO							2		
Pump Performance	4	R	A								4	3MO							4		
Pump on Indication	4	R	B								4	3MO							4		
Water Storage Pressure	2	R	A				1/S	2			2	3MO							2		
Shutoff Valve Position	20	R	B								20	3MO							20		
Storage Tank Quantity	10	R	A	10							10	3MO					10	1/H	10		
Storage Tank Temperature	10	R	A				1/S	2			10	3MO							10		
Bacteria Filter Performance	6	R	A								6	3MO					6	1/H	6		Shows filter degradation.
Water Transfer Flow	2	R	A								2	3MO	1/S				2	1/H	2	1/S	Shows H_2O transfer from potable to fresh.
Potable Water Use Rate	2	R	A								2	3MO					2	1/H	2		Needed for mass balance.
Fresh Water Flow Rate	2	R	A								2	3MO	1/S				2	1/H	2	1/S	Needed for mass balance.
Controller Output	2	R	B								2	3MO							2		
Controller Stimulus	2	S	B								2	3MO							2		
WASTE MANAGEMENT																					
URINE COLLECTION																					
Air Outlet Moisture	10	R	B				1/S		10		10	3MO							10		Indicates possible cabin contamination.
FECAL WASTE COLLECTION																					
Control Stimulus	4	S	B								4	3MO							4		
Fecal Container Pressure	4	R	A				1/S	4			4	3MO							4		
Fecal Container Moisture	4	R	B				1/S		4		4	3MO							4		
Vacuum Pump Performance	4	R	A								4	3MO							4		
Vacuum Pump on Indication	4	R	B								4	3MO							4		
Deflection Motor on Indication	4	R	B								4	3MO							4		
Blower Flow Rate	4	R	A								4	3MO	1/S						4	1/S	
Blower Performance	4	R	A								4	3MO							4		

Q-Quantity
S-Stimulus
R-Response

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P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
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Table I-4

SUBSYSTEM: EC/LS (Cont'd)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Blower on Indication	4	R	B								4	3MO							4		Not in continuous use; not an LMDU interface.
IVA/EVA																					Used only periodically - unit contains certain amount of own instrumentation.
PORTABLE LIFE SUPPORT SYSTEM																					
Suit Pressure	4	R	A				1/S		4		4	3MO							4		
Primary O_2 Pressure	4	R	A				1/S		4		4	3MO							4		
Primary O_2 Motor Circuit	4	R	A				1/S		4		4	3MO							4		
Feed Water Pressure	4	R	A				1/S		4		4	3MO							4		
Circulating Liquid Inlet Temp.	4	R	A				1/S		4		4	3MO							4		
Sublimator Gas Outlet Temp.	4	R	A				1/S		4		4	3MO							4		
Water Temperature	4	R	A				1/S		4		4	3MO							4		
UMBILICAL LIFE SUPPORT																					
Emergency O_2 Bottle Pressure	24	R	A				1/S		24		24	3MO							24		
Emergency O_2 Regulator Press.	12	R	A				1/S		12		12	3MO							12		
Oxygen Flow Rate	12	R	A				1/S		12		12	3MO	1/S						12	1/S	
Oxygen Temperature	36	R	A				1/S		36		36	3MO							36		
Bypass Regulator Press Drop	12	R	A				1/S		12		12	3MO							12		
Suit Inlet O_2 Pressure	12	R	A				1/S		12		12	3MO							12		
Circulating Water Inlet Temp.	12	R	A				1/S		12		12	3MO							12		
Circulating Water Outlet Temp.	12	R	A				1/S		12		12	3MO							12		
IVA SUPPORT																					
Accumulator Pressure	4	R	A				1/S		4		4	3MO							4		
Diverter Valve Position	4	R	B				1/S		4		4	3MO							4		
Relief Valve Pressure Diff.	4	R	A				1/S		4		4	3MO							4		
THERMAL CONTROL																					Critical function for most space station equipment.
COOLANT WATER CIRCULATION																					
Accumulator Pressure	2	R	A				1/S			2	2	3MO							2		
Gas Separator Moisture	2	R	B				1/S	2			2	3MO							2		

Q-Quantity, S-Stimulus, R-Response
A-Analog, B-Bilevel, D-Digital
P-Pulse, R-RF, SI-Sampling Interval, SR-Sampling Rate
S-Second, M-Minute, H-Hour, D-Day, W-Week, MO-Month

Table I-4

SUBSYSTEM: EC/LS (Cont'd)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING	Non Crit	Caution	Warning	PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Pump Performance	4	R	A				1/S	2			4	3MO							4		
Pump on Indication	4	R	B								4	3MO							4		
RADIATOR CONTROL																					
Freon Fixed Temperature	40	R	A				1/S			4	40	3MO					4	1/H	40		Check performance and condition of freon loop.
Flow Reversal Valve Position	16	R	B								16	3MO							16		
Flow Reversal Valve Control	16	S	B								16	3MO							16		
Isolation Valve Position	32	R	A								32	3MO							32		
Isolation Valve Control	4	S	B								4	3MO							4		
RADIATOR RECIRCULATION																					
Accumulator Pressure	8	R	A				1/S			8	8	3MO							8		
Freon Inlet Temperature	8	R	A				1/S	8			8	3MO							8		
Freon Flow Rate	8	R	A				1/S	8			8	3MO	1/S						8	1/S	
Gas Separator Moisture	8	R	B				1/S	8			8	3MO							8		
Pump Performance	16	R	A				1/S	8			16	3MO							16		
Pump Control	16	S	B								16	3MO							16		
COOLANT WATER CONTROL																					
Controller Output	2	R	A								2	3MO							2		
Temperature Sensor Output	4	R	A								4	3MO							4		
Controller Stimulus	2	S	A								2	3MO							2		
MISCELLANEOUS																					
Water Temperature	29	R	A				1/S	4			29	3MO					4	1/H	29		Monitor thermal control performance.
Coolant Water Flow	2	R	A				1/S	2			2	3MO	1/S						2	1/S	Needed for vehicle heat balance.
Freon Temperature	4	R	A								4	3MO							4		Needed for vehicle heat balance.
Freon Flow to Radiator	4	R	A								4	3MO							4		Needed for vehicle heat balance.

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Table I-4

SUBSYSTEM: EC/LS (Cont'd) — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
BRAYTON CYCLE EPS ONLY																					
ATMOSPHERE RECONDITIONING																					
CO_2 CONTROL																					
3-way Valve Position	4	R	B								4	3MO							4		
Hot Circulating Fluid Temp	2	R	A								2	3MO							2		
Hot Circulating Fluid Flow	2	R	A								2	3MO	1/S						2	1/S	
WATER MANAGEMENT																					
URINE WATER RECOVERY																					
Heating Fluid Inlet Temp	2	R	A								2	3MO							2		
Bypass Valve Position	2	R	B								2	3MO							2		
Bypass Valve Sensor Response	2	R	A								2	3MO							2		
Bypass Valve Control	2	S	A								2	3MO							2		
WATER STORAGE																					
Heating Water Inlet Temp	2	R	A								2	3MO							2		
Temp Valve Sensor Output	10	R	A								10	3MO							10		
WASTE MANAGEMENT																					
FECAL WASTE COLLECTION																					
Heating Water Inlet Temp	4	R	A								4	3MO							4		
THERMAL CONTROL																					
HEATING WATER CIRCUIT																					
Water Flow Rate	2	R	A				1/S		2		2	3MO	1/S						2	1/S	
Pump Inlet Temperature	2	R	A								2	3MO							2		
Accumulator Pressure	2	R	A				1/S	2			2	3MO							2		

Q-Quantity A-Analog P-Pulse S-Second
S-Stimulus B-Bilevel R-RF M-Minute
R-Response D-Digital SI-Sampling Interval H-Hour
SR-Sampling Rate D-Day
W-Week
MO-Month

Table I-4

SUBSYSTEM: EC/LS (Cont'd) Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
BRAYTON CYCLE EPS ONLY (Cont'd)																					
Gas Separator Moisture	2	R	B				1/S	2			2	3MO							2		
Pump Performance	4	R	A								4	3MO							4		
Pump On Indication	4	R	B								4	3MO							4		
HEATING WATER CONTROL																					
Water Outlet Temp	2	R	A				1/S		2		2	3MO							2		
Water Inlet Temp	4	R	A								4	3MO							4		
Pressure Relief Vlv Moisture	2	R	B				1/S	4			2	3MO							2		

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P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
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Table I-5

SUBSYSTEM: COMMUNICATIONS	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
Measurement/stimulus signal				Q	SI	SR	SR	Non Crit Q	Caution Q	Warning Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
S-BAND VIDEO RECEIVERS																					(1)Determined by operational duty cycle.
Primary Power Control	10	S	B	10	(1)						10	1MO							10		(2)Continuously available when operating.
Primary Power On/Off	10	R	B	10	(2)						10	1MO							10		
AGC Stimulus	10	(3) S	R								10	1MO					10	(4) 1/D	10		(3)All analog and RF stimuli generated internal to communications subsystem.
AGC Output Level	10	R	A				(5) 1/M	10			10	1MO					10	(4) 1/D	10		(4)For detecting graceful degradation; check against previous 30 sample points; retain 30 sample point averages.
Modulation Input Stimulus	10	(3) S	R								10	1MO							10		(5)For detecting an abrupt change (wide limits)need to monitor only when operating.
Modulation Output Present	10	R	B								10	1MO							10		
S-BAND VIDEO RECEIVER MODEMS																					
Primary Power Control	10	S	B	10	(1)						10	1MO							10		
Primary Power On/Off	10	R	B	10	(2)						10	1MO							10		
Modulation Input Stimulus	10	(3) S	A								10	1MO							10		
Modulation Output Present	10	R	B								10	1MO							10		
Video Channel Select	10	S	D	10	(1)														10		
Video Channel Select	10	R	D	10	(2)														10		
S-BAND DATA RECEIVERS																					
Primary Power Control	10	S	B	10	(1)						10	1MO							10		
Primary Power On/Off	10	R	B	10	(2)						10	1MO							10		
AGC Stimulus	10	(3) S	R								10	1MO					10	(4) 1/D	10		
AGC Output Level	10	R	A				(5) 1/M	10			10	1MO					10	(4) 1/D	10		
Modulation Input Stimulus	10	(3) S	R								10	1MO							10		
Modulation Output Present	10	R	B								10	1MO							10		
S-BAND PM RECEIVERS																					
Primary Power Control	2	S	B	2	(1)						2	1W							2		
Primary Power On/Off	2	R	B	2	(2)						2	1W							2		
AGC Stimulus	2	(3) S	R								2	1W					2	(6) 1/H	2		(6)For detecting graceful degradation; check against previous 48 samples; retain daily average for 3 months.
AGC Output Level	2	R	A				(5) 1/M	2			2	1W					2	(6) 1/H	2		
Modulation Output Present	2	(3) S	R								2	1W							2		

Q-Quantity A-Analog P-Pulse S-Second
S-Stimulus B-Bilevel R-RF M-Minute
R-Response D-Digital SI-Sampling Interval H-Hour
SR-Sampling Rate D-Day
W-Week
MO-Month

Table I-5

SUBSYSTEM: COMMUNICATIONS	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING	Non Crit	Caution	Warning	PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
Measurement stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Modulation Output Present	2	R	B								2	1W							2		
Ku-Band FM Exciters																					
Primary Power Control	2	S	B	2	(1)						2	1W							2		
Primary Power On/Off	2	R	B	2	(2)						2	1W							2		
RF Power Output Level	2	R	A				(5) 1/M	2			2	1W					2	(6) 1/H	2		
Modulation Input Stimulus	2	(3) S	A								2	1W							2		
Modulation Output	2	R	B								2	1W							2		
KU-BAND FM TRANSMITTER MODEMS																					
Primary Power Control	2	S	B	2	(1)						2	1W							2		
Primary Power On/Off	2	R	B	2	(2)						2	1W							2		
Modulation Input Stimulus	2	(3) S	A								2	1W							2		
Modulation Input Stimulus	2	S	D								2	1W							2		
Modulation Output Present	2	R	B								2	1W							2		
Voice Mode Control	2	S	B	2	(1)														2		
Voice On/Off	2	R	B	2	(2)														2		
Data Mode Control	2	S	B	2	(1)														2		
Data On/Off	2	R	B	2	(2)														2		
TV Mode Control	2	S	B	2	(1)														2		
TV ON/OFF	2	R	B	2	(2)														2		
TV Channel Select Control	2	S	D	2	(1)														2		
TV Channel Selected	2	R	D	2	(2)														2		
S-BAND FM RECEIVERS																					
Primary Power Control	2	S	B	2	(1)						2	1W							2		
Primary Power On/Off	2	R	B	2	(2)						2	1W							2		
AGC Stimulus	2	(3) S	R								2	1W					2	(6) 1/H	2		
AGC Output Level	2	R	A				(5) 1/M	2			2	1W					2	(6) 1/H	2		
Modulation Input Stimulus	2	(3) S	R								2	1W							2		
Modulation Output Present	2	R	B								2	1W							2		

Q-Quantity
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P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

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M-Minute
H-Hour
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Table I-5

SUBSYSTEM: COMMUNICATIONS (Cont'd) Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
				Q	SI	SR	SR	Non Crit Q	Caution Q	Warning Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
S-BAND FM RECEIVER MODEMS																					
Primary Power Control	2	S	B	2	(1)						2	1W							2		
Primary Power On/Off	2	R	B	2	(2)						2	1W							2		
Modulation Input Stimulus	2	(3) S	A								2	1W							2		
Modulation Output Present	2	R	B								2	1W							2		
Voice/Entertainment Mode Control	2	S	B	2	(1)														2		
Voice/Entertainment On/Off	2	R	B	2	(2)														2		
Data Mode Control	2	S	B	2	(1)														2		
Data On/Off	2	R	B	2	(2)														2		
Television Mode Control	2	S	B	2	(1)														2		
Television On/Off	2	R	B	2	(2)														2		
TV Channel Select Control	2	S	D	2	(1)														2		
TV Channel Select	2	R	D	2	(2)														2		
KU-BAND POWER AMPLIFIER																					
Primary Power Control	5	S	B	5	(1)						5	1W							5		
Primary Power On/Off	5	R	B	5	(2)						5	1W							5		
PA Warmup Cycle Complete	5	R	B	5	(2)						5	1W							5		
RF Power Input Stimulus	5	(3) S	R																5		
RF Power Output Level	5	R	A				(5) 1/M	5			5	1W					5	(6) 1/H	5		
VSWR Level	5	R	A								5	1W							5		
KU-BAND FM EXCITERS																					
Primary Power Control	5	S	B	5	(1)						5	1W							5		
Primary Power On/Off	5	R	B	5	(2)						5	1W							5		
RF Power Output Level	5	R	A				(5) 1/M	5			5	1W					5	(6) 1/H	5		
Modulation Input Stimulus	5	(3) S	A								5	1W							5		
Modulation Output	5	R	B								5	1W							5		

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Table I-5

SUBSYSTEM: COMMUNICATIONS (Cont'd) — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
S-BAND FM TRANSPONDER																					
Primary Power Control	2	S	B	2	(1)						2	1W							2		
Primary Power On/Off	2	R	B	2	(2)						2	1W							2		
Ranging Channel Control	2	S	B	2	(1)														2		
Ranging Channel Inhibit	2	R	B	2	(2)														2		
Local Oscillator Control	2	S	B	2	(1)														2		
Local Oscillator Enable	2	R	B	2	(2)														2		
AGC Stimulus	2	(3) S	R								2	1W					2	(4) 1/D	2		
AGC Output Level	2	R	A				(5) 1/M	2			2	1W					2	(4) 1/D	2		
Receiver Loop Lock Indication	2	R	B	2	(2)						2	1W							2		
RF Power Output Level	2	R	A				(5) 1/M	2			2	1W					2	(6) 1/H	2		
Modulation Input Stimulus	2	(3) S	A								2	1W							2		
Modulation Output Present	2	R	B								2	1W							2		
VSWR Level	2	R	A								2	1W							2		
S-BAND FM TRANSPONDER MODEM																					
Primary Power Control	2	S	B	2	(1)						2	1W							2		
Primary Power On/Off	2	R	B	2	(2)						2	1W							2		
1.25 MHZ Subcarrier Control	2	S	B	2	(1)														2		
1.25 MHZ Subcarrier On/Off	2	R	B	2	(2)														2		
Emergency Voice Control	2	S	B	2	(1)														2		
Emergency Voice On/Off	2	R	B	2	(2)														2		
70 KHZ Subcarrier Control	2	S	B	2	(1)														2		
70 KHZ Subcarrier On/Off	2	R	B	2	(2)														2		
30 KHZ Subcarrier Control	2	S	B	2	(1)														2		
30 KHZ Subcarrier On/Off	2	R	B	2	(2)														2		
S-BAND POWER AMPLIFIER																					
Primary Power Control	2	S	B	2	(1)						2	1W							2		

Q-Quantity, S-Stimulus, R-Response
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S-Second, M-Minute, H-Hour, D-Day, W-Week, MO-Month

Table I-5

SUBSYSTEM: COMMUNICATIONS (Cont'd)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Primary Power On/Off	2	R	B	2	(2)						2	1W							2		
PA Warmup Cycle Complete	2	R	B	2	(2)						2	1W							2		
RF Power Input Stimulus	2	(3) S	R																2		
RF Power Output Level	2	R	A				(5) 1/M	2			2	1W					2	(6) 1/H	2		
VSWR Level	2	R	A								2	1W							2		
S-BAND FM EXCITER																					
Primary Power Control	2	S	B	2	(1)						2	1W							2		
Primary Power On/Off	2	R	B	2	(2)						2	1W							2		
RF Power Output Level	2	R	A				(5) 1/M	2			2	1W					2	(6) 1/H	2		
Modulation Input Stimulus	2	(3) S	A								2	1W							2		
Modulation Output	2	R	B								2	1W							2		
S-BAND TRANSMITTER MODEM																					
Primary Power Control	2	S	B	2	(1)						2	1W							2		
Primary Power On/Off	2	R	B	2	(2)						2	1W							2		
Modulation Input Stimulus	2	(3) S	A								2	1W							2		
Modulation Input Stimulus	2	S	D								2	1W							2		
Modulation Output Present	2	R	B								2	1W							2		
Data Mode Control	2	S	B	2	(1)														2		
Data On/Off	2	R	B	2	(2)														2		
TV Mode Control	2	S	B	2	(1)														2		
TV On/Off	2	R	B	2	(2)														2		
TV Channel Select Control	2	S	D	2	(1)														2		
TV Channel Selected	2	R	D	2	(2)														2		
VHF VOICE/RANGING XMTRS																					
Primary Power Control	2	S	B	2	(1)						2	1MO							2		
Primary Power On/Off	2	R	B	2	(2)						2	1MO							2		
RF Power Output Level	2	R	A				(5) 1/M	2			2	1MO					2	(6) 1/H	2		

Q-Quantity
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R-Response

A-Analog
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D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
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Table I-5

SUBSYSTEM: COMMUNICATIONS (Cont'd) — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
VSWR Level	2	R	A								2	1MO							2		
Modulation Input Stimulus	2	(3) S	A								2	1MO							2		
Modulation Input Stimulus	2	S	D								2	1MO							2		
Modulation Output	2	R	B								2	1MO							2		
VHF VOICE/RANGING RCVRS																					
Primary Power Control	2	S	B	2	(1)						2	1MO							2		
Primary Power On/Off	2	R	B	2	(2)						2	1MO							2		
AGC Stimulus	2	(3) S	R								2	1MO					2	(4) 1/D	2		
AGC Output Level	2	R	A				(5) 1/M	2			2	1MO					2	(4) 1/D	2		
Modulation Input Stimulus	2	(3) S	R								2	1MO							2		
Modulation Output Present	2	R	B								2	1MO							2		
VHF VOICE TRANSCEIVER MODEMS																					
Primary Power Control	2	S	B	2	(1)						2	1MO							2		
Primary Power On/Off	2	R	B	2	(2)						2	1MO							2		
Voice Mode Control	2	S	B	2	(1)														2		
Voice Mode On/Off	2	R	B	2	(2)														2		
Squelch Control	2	S	B	2	(1)														2		
Squelch Override/Enable	2	R	B	2	(2)														2		
Ranging Mode Control	2	S	B	2	(1)														2		
Ranging On/Off	2	R	B	2	(2)														2		
Modulation Input Stimulus	2	(3) S	A								2	1MO							2		
Modulation Output Present	2	R	B								2	1MO							2		
VHF DATA RECEIVERS																					
Primary Power Control	2	S	B	2	(1)						2	1MO							2		
Primary Power On/Off	2	R	B	2	(2)						2	1MO							2		
AGC Stimulus	2	(3) S	R								2	1MO					2	(4) 1/D	2		
AGC Output Level	2	R	A				(5) 1/M	2			2	1MO					2	(4) 1/D	2		

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Table I-5

SUBSYSTEM: COMMUNICATIONS (Cont'd) — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Modulation Input Stimulus	2	(3) S	R								2	1MO							2		
Modulation Output Present	2	R	B								2	1MO							2		
RANGING MODEM																					
Primary Power Control	2	S	B	2	(1)						2	1MO							2		
Primary Power On/Off	2	R	B	2	(2)						2	1MO							2		
Shuttle Ranging Control	2	S	B	2	(1)														2		
Shuttle Ranging On Off	2	R	B	2	(2)														2		
FFM Ranging Control	2	S	B	2	(1)														2		
FFM Ranging On/Off	2	R	B	2	(2)														2		
FFM Receiver Select Control	2	S	D	2	(1)														2		
FFM Receiver Selected	2	R	D	2	(2)														2		
Code Correlation Lock In/Out	2	R	B	2	(2)						2	1MO							2		
Range Code Stimulus	2	S	D								2	1MO							2		Known time delay required.
Range Data Readout	2	R	D								2	1MO							2		
Ranging Modulation Present	2	R	B								2	1MO							2		
VHF FM TRANSMITTERS																					
Primary Power Control	3	S	B	3	(1)						3	1MO							3		
Primary Power On/Off	3	R	B	3	(2)						3	1MO							3		
RF Power Output Level	3	R	A				(5) 1/M	3			3	1MO					3	(6) 1/H	3		
VSWR Level	3	R	A								3	1MO							3		
Modulation Input Stimulus	3	(3) S	A								3	1MO							3		
Modulation Output	3	R	B								3	1MO							3		
VHF FM RECEIVERS																					
Primary Power Control	3	S	B	3	(1)						3	1MO							3		
Primary Power On/Off	3	R	B	3	(2)						3	1MO							3		
AGC Stimulus	3	(3) S	R								3	1MO					3	(4) 1/D	3		
AGC Output Level	3	R	A				(5) 1/M	3			3	1MO					3	(4) 1/D	3		

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Table I-5

SUBSYSTEM: COMMUNICATIONS (Cont'd)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLA-TION		REMARKS
Measurement/stimulus signal				Q	SI	SR	SR	Non Crit Q	Cau tion Q	Warn ing Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Modulation Input Stimulus	3	(3) S	R								3	1MO							3		
Modulation Output Present	3	R	A								3	1MO							3		
VHF FM XMTR/RCVR MODEMS																					
Primary Power Control	3	S	B	3	(1)						3	1MO							3		
Primary Power On/Off	3	R	B	3	(2)						3	1MO							3		
Modulation Input Stimulus	3	(3) S	A								3	1MO							3		
Modulation Output Present	3	R	B								3	1MO							3		
Voice Mode Control	3	S	B	3	(1)														3		
Voice On/Off	3	R	B	3	(2)														3		
Biomed Mode Control	3	S	B	3	(1)														3		
Biomed On/Off	3	R	B	3	(2)														3		
Squelch Control	3	S	B	3	(1)														3		
Squelch Enable/Override	3	R	B	3	(2)														3		
Vox Mode Control	2	S	B	2	(1)														2		
Vox Enable/Override	2	R	B	2	(2)														2		
HIGH GAIN ANTENNA SYSTEM																					
Ku-Band Preamp/mixer/L.O. Primary Power Control	16	S	B	16	(1)						16	1W							16		
Ku-Band Preamp/mixer/L.O. Primary Power	16	R	B	16	(2)						16	1W							16		
Ku-Band Preamp/mixer/L.O. Select Control	16	S	B	16	(1)						16	1W							16		
Ku-Band Preamp/mixer/L.O. Selected	16	R	B	16	(2)						16	1W							16		
Preamp/Mixer/L.O. RF Input Stimulus	4	(3) S	R								4	1W							4		
Preamp/Mixer/L.O. Output Level	4	R	A								4	1W							4		
Antenna Select Control	24	S	B	24	(1)														24		
Antenna Selected	24	R	B	24	(2)														24		
Feed RF Power Level	8	R	A								8	1W		8		(7)			8		
Antenna Position Control Input	8	S	D								8	1W							8		(7) Determine system insertion loss after component replacement (install, verification)

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Table I-5

SUBSYSTEM: COMMUNICATIONS (Cont'd) — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Antenna Position Output	8	R	D								8	1W							8		
Acquisition/Main Antenna Override/Auto Control	8	S	B	8	(1)														8		
Acquisition/Main Antenna Override/Auto Selected	8	R	B	8	(2)														8		
Feed VSWR Level	8	R	A								8	1W							8		
S-BAND LOW GAIN ANTENNA SYSTEM																					
Antenna Select Control	2	S	B	2	(1)														2		
Antenna Selected	2	R	B	2	(2)														2		
RF Power Level at Antenna Elements	4	R	A								4	1W		4		(7)			4		
VSWR Level at Antenna Elements	4	R	A								4	1W							4		
VHF LOW GAIN ANTENNA SYSTEM																					
Antenna Select Control	2	S	B	2	(1)														2		
Antenna Selected	2	R	B	2	(2)														2		
RF Power Level at Antenna Elements	4	R	A								4	1MO		4		(7)			4		
VSWR Level at Antenna Elements	4	R	A								4	1MO							4		
KU-BAND LOW GAIN ANTENNA SYSTEM																					
Preamp/Mixer/L.O. Primary Power Control	2	S	B	2	(1)						2	1MO							2		
Preamp/Mixer/L.O. Primary Power On/Off	2	R	B	2	(2)						2	1MO							2		
Preamp/Mixer/L.O. RF Input Stimulus	2	(3) S	R								2	1MO							2		
Preamp/Mixer/L.O. Output Level	2	R	A								2	1MO							2		
Antenna Select Control	6	S	B	6	(1)														6		
Antenna Selected	6	R	B	6	(2)														6		
RF Power Level at Antenna Elements	8	R	A								8	1MO		8		(7)			8		
VSWR Level at Antenna Elements	8	R	A								8	1MO							8		
VHF DATA TRANSMITTERS																					
Primary Power Control	2	S	B	2	(1)						2	1MO							2		
Primary Power On/Off	2	R	B	2	(2)						2	1MO					2	(4) 1/D	2		
RF Power Output Level	2	R	A				(3) 1/M	2			2	1MO					2	(4) 1/D	2		
VSWR Level	2	R	A								2	1MO							2		
Modulation Input Stimulus	2	S	D								2	1MO							2		
Modulation Output	2	R	B								2	1MO							2		

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S-Second, M-Minute, H-Hour, D-Day, W-Week, MO-Month

Table I-6

SUBSYSTEM: STRUCTURES	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
DOCKING MECHANISM																					
Docking Ring Position (Extended)	7	R	B	7							7	(1)							7		(1)Once per event (~ 1/position/mo)
Docking Ring Position (Retracted)	7	R	B	7							7	(1)							7		
Docking Ring Strut Pressure	7	R	A								7	(1)	1/S						7		
Docking Port Seal Pressure	14	R	A								14	10							14		
Docking Port Cover Control	7	S	A	7							7	(1)							7		
Docking Port Cover Position	7	R	A	7							7	(1)							7		
HATCHES, AIRLOCK AND VIEWPORTS																					
Hatch Position (Open)	16	R	B	16							16	8H							16		
Hatch Position (Closed)	16	R	B	16							16	8H							16		
Hangar Temperature (Remote)	2	R	A				(2) 1/S	2											2		(2)Estimated max duration of 1 wk/mo
Hangar Pressure (Remote)	2	R	A				(2) 1/S	2											2		
Hangar Door Control	1	S	B	1							1	1MO							1		
Hangar Door Position (Open)	1	R	B	1							1	8H							1		
Hangar Door Position (Closed)	1	R	B	1							1	8H							1		
ARTIFICIAL GRAVITY EXP PROVISIONS																					Only during artificial g period.
Spoke Pressure Supply	1	R	A				1/S	1			1	3MO	1/S						1		
Spoke Internal Pressure	1	R	A				1/S	1			1	3MO	1/S						1		
Despin Module Rotation Control	1	S	A	1							1	3MO							1		
Despin Module Rate	1	R	A	1			1/S	1			1	3MO	1/S						1		
Despin Module Power	1	R	A	1							1	3MO							1		
S-II Stage Latches (unlatched)	4	R	B	4							4	3MO							4		
S-II Stage Latch Control (Latched)	1	S	B	1							1	3MO							1		
S-II Stage Latch Control (Unlatched)	1	S	B	1							1	3MO							1		
S-II Stage Latches (Latched)	4	R	B	4							4	3MO							4		
Cable Deployment Module Drive Control	1	S	A	1							1	3MO							1		
Cable Deployment Module Drum Travel	1	R	A	1							1	3MO							1		

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S-Second, M-Minute, H-Hour, D-Day, W-Week, MO-Month

Table I-6

SUBSYSTEM: STRUCTURES (Cont'd)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Cable Deployment Module Strut Ring Position	1	B	A	1							1	3MO							1		
Cable Deployment Module Power Monitor	1	R	A								1	3MO							1		
Cable Deployment Module Docking Latches	1	B	B	1	(3)														1		(3) One time only event.
ANTENNA DEPLOYMENT																					
Boom Launch Stowage Position Lock Status	4	R	B	4	(3)														4		
Antenna Launch Stowage Lock Control	4	S	B	4	(3)														4		
Boom Position	4	R	A	4															4		
Boom Deployment Position Lock Status	4	R	B	4															4		
Boom Deployment Lock Control	4	S	B	4															4		
Boom Maintenance Position Lock Status	4	R	B																4		
Boom Maintenance Position Lock Control	4	S	B																4		
Drive Unit Power Monitor	4	R	A																4		
Drive Unit Control	4	S	A	4															4		
ISOTOPE POWER SYSTEM HDLG & REPL EQPMT																					Use limited to isotope unit removal/replacement operation(~once every 2½ yrs).
Drive Unit Power Monitor	2	R	A																2		

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Table I-7

SUBSYSTEM: EPS-I/BR Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
SHIELD																					(Backup to emergency cooling mode)
Shield Position	2	R	B								2	3MO									Normally closed.
Shield Drive Motor Torque	2	R	A								2	3MO					2	(1)			Normally zero. (1)Operates only for periodic c/o or emergency.
Shield Drive Motor Start	2	S	B								2	3MO									
POWER CONVERSION SYSTEM																					(2)Trend for degradation indication.
HRHX Coolant Inlet Temp (T7)	2	R	A														2	(2) 1/MO			Nominal 325°F, range to 400°F. (Heat Rejection Heat Exchanger).
Compressor Inlet Temp (T8)	6	R	A				1/M		2										6		Nominal 100°F, caution at 1450°F (10% power change used for start, stop, and isolating fault between PCS & heat reject. system
Recuperator Outlet Temp (T15)	2	R	A														2	(2) 1/MO			Nominal 340°F, range to 900°F.
Compressor Outlet Pressure (P3)	6	R	A				1/M		2										6		Nominal 58 psia, caution at 46 psia (10% power change) used to direct low inventory and in start, stop, sequence.
Pressure Switch	4	R	B																4		Makeup gas control signal to gas mgmt. system valve.
Alternator Hot Spot Temp (T14)	6	R	A				1/S		2										6		For alternate protection, caution 300°F.
Bearing Cavity Pressure (P6)	6	R	A				1/S		2										6		For bearing protection, caution at 46 psia, nominal 58 psia.
Turbine Inlet Temp (T12)	6	R	A				1/S		2										6		Heat source, ready state for start & shut-down nominal 1600°F; caution at 10% power change (1510 or 1700).
PCS Gas Loop Flow Rate (F4)	2	R	A								2	1MO					2	1/W	2		Trend for loop degradation, retain 1 yr's data.
GAS MANAGEMENT SYSTEM																					
Gas Storage Temp (T16)	2	R	A				1/S	2											2		Out of limits when 400°F or -100°F; 200°F nominal.
Heater Contactor (K3)	2	R	B																2		Based on gas temperature (200°F).
Gas Storage Pressure (P7)	2	R	A				1/S		2								2	1/W	2		Nominal 1700 psia, 0-2000 psia range.
Backup Jacking Gas Thrust Bearing Vlv (Sys)	2	R	B	2															2		
Backup Jacking Gas Journal Bearing Vlv (Sys)	2	R	B	2															2		Valve positions - normally closed; used
Primary Jacking Gas Thrust Bearing Vlv (Sys)	2	R	B	2															2		during start, stop, and underspeed.
Primary Jacking Gas Journal Bearing Vlv (Sys)	2	R	B	2															2		
Thrust Bearing Pressure Switch	2	R	B	2															2		Indicate under pressure for jacking
Journal Bearing Pressure Switch	2	R	B	2															2		gas initiation.

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Table I-7

SUBSYSTEM: EPS-I/BR	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
Measurement/stimulus signal								Non Crit	Caution	Warning											
				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
HEAT REJECTION SYSTEM																					
Pump Motor Volts In (V2, V3)	4	R	A																4		
Pump Motor Current In. (A5,A6)	4	R	A														2	(3) 1/W	4		(3) Trend for degradation, retain 1 year's data.
Pump Motor Pressure Out (P1)	4	R	A														2	(3) 1/W	4		
Electronic Cold Plate Cooling Flow Rate (F1)	4	R	A																4		
Alternator Cooling Flow Rate (F2)	4	R	A																4		
Waste HX Cooling Flow Rate(F3)	4	R	A																4		
Cold Plate Temp. Out. Cooling (T4)	4	R	A																4		
Alternator Temp. Out. Cooling (T5)	4	R	A																4		
Waste HX Temp. Out. Cooling (T7)	4	R	A																4		
Signal Conditioner Hot Spot (T3)	6	R	A				1/S		2										6		Caution at > 180° F.
Motor Pump Hot Spot (T6)	6	R	A				1/S		2										6		Caution at > 180° F.
Radiator Coolant Disch. (T2)	4	R	A														2	(3) 1/W	4		
HEAT SOURCE																					
Fuel Capsule Temp (T17)	6	R	A				1/S		2	2							1	(3) 1/W	6		Caution at 2100° F, warning at 2500° F, nominal is 1900° F.
IRV Position Sensor and Drive	12	R	B																12		Normally closed.
BeO Heat Sink Temp (T18)	6	R	A				1/S		2	2									6		Backup to T17.
IRV Ejection Contact Switch	2	R	B	2							2	3MO							2		
IRV Separation Firing Device	2	R	B	2							2	3MO							2		
Radio Beacon Check Circuitry	2	R	B	2							2	3MO							2		
Flashing Light Check Circuitry	2	R	B	2							2	3MO							2		
Dye Marker Circuitry	2	R	B	2							2	3MO							2		
Ballute Release Device	2	R	B	2							2	3MO							2		

Q-Quantity
S-Stimulus
R-Response

A-Analog
B-Bilevel
D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
W-Week
MO-Month

Table I-7

SUBSYSTEM: EPS-I/BR (Cont'd) Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
CONTROL AND MONITORING																					
Alternator Series Field Current (A1)	2	R	A																2		
Alternator Shunt Field Current (A2)	2	R	A																2		
Current to Source Bus (A3)	6	R	A																6		Detects 3Ø volt. for over & under volt. protection & for volt. reg. excitor.
Alternator Gross Current (A4)	6	R	A				1/S		2		6	1MO							6		Detects 3Ø current for overcurrent protection; caution at 35% of 13.5 amps.
Shunt Contactors (X1, X2)	4	R	B	4															4		Used for startup and shutdown control.
Alternator Voltage (V1)	6	R	A				1/S		2		6	1MO							6		Caution at ± 1% of 120 volts.
Emergency Shutdown Signal	2	R	A				1/S			2											
Speed Control Signals	6	S	A				1/S		2	2									6		Nominal frequency 1200 Hz; caution at -10%; warning at +15% (overspeed).
Signal Conditioning Module Reference Voltage	2	R	A				1/S		2										2		

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S–Second
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Table I-8

SUBSYSTEM: EPS (TCD) I/Br BASELINE CONFIG. — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
ALTERNATOR FEEDERS																					
Current	6	R	A	6			6/M	6			6	1W					6	(1) 4/H	6		Used to check load sharing between alternators
ALTERNATOR FEEDER CB'S																					(1) To generate short term load profile; retain data for two weeks
Position	4	S	B																4		Emergency override command capability
Position	4	R	B				5/S		4										4		Open breaker results in loss of ½ power source
ALTERNATOR FEEDER/SOURCE BUS DIFFERENTIAL PROTECTION RELAYS																					
Current	6	S	A								6	6MO							6		Trip relay but not breaker
Relay Trip	6	R	B				1/S	6											6		Relay trip trips alt. C/B and associate source bus C/B's
SOURCE BUS																					
Voltage	6	R	A				6/M	6			6	1W					12	(2) 4/D	6		(2) Check against previous week's data; retain previous two week's data.
SOURCE BUS TO DISTRIBUTOR NO. 2 1200 Hz POWER TRANSMISSION CABLES																					
Current	12	R	A								12	1W							12		
DISTRIBUTOR NO. 2 TO DISTRIBUTOR NO. 1 1200 Hz POWER TRANSMISSION																					
Current																					
Current	6	R	A								6	1W							6		
1200 Hz TRANSMISSION CABLES DIFFERENTIAL PROTECTION RELAYS																					
Current	12	S	A								12	6MO							12		Trip relay and breaker (typical for all differential relays except alternator feeder/source bus relays)
Relay Trip	12	R	B				1/M	12											12		
1200 HZ TRANSMISSION CABLE CB'S																					
Position	16	S	B								16	3 Mo							16		Test remote trip circuit (typical all commandable breakers except alternator feeder breakers)
Position	16	R	B				2/M	16											16		
1200 HZ TRANSMISSION CABLE SWITCHES																					
Position	4	S	B								4	3MO							4		
Position	4	R	B				2/M	4											4		
MAIN 1200 HZ DISTRIBUTOR BUSES																					
Voltage	4	R	A				6/M	4			4	1W							4		
MAIN 1200 HZ DISTRIBUTOR BUS POWER SWITCHES																					

Q-Quantity A-Analog P-Pulse S-Second
S-Stimulus B-Bilevel R-RF M-Minute
R-Response D-Digital SI-Sampling Interval H-Hour
SR-Sampling Rate D-Day
W-Week
MO-Month

Table I-8

SUBSYSTEM: EPS (TCD) (Cont.)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
Measurement/stimulus signal				Q	SI	SR	SR	Non Crit Q	Caution Q	Warning Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Position	12	S	B								12	3MO							12		
Position	12	R	B				2/M	12											12		
MAIN 1200 HZ DISTRIBUTOR BUS SELECTOR SWITCHES																					
Position	9	S	B								9	1MO							9		
Position	9	R	B																9		
MAIN 1200 HZ DISTRIBUTOR BUS CB'S																					
Position	44	S	B								44	3MO							44		
Position	44	R	B				2/M	44											44		
1200 HZ FEEDERS TO DISTRIBUTION PANELS (LOAD BUSES)																					
Current	12	R	A								12	1W							12		
1200 HZ LOAD BUSES																					
Voltage	4	R	A				6/M	4			4	1W							4		
1200 HZ DISTRIBUTION FEEDER CB'S																					
Position	8	S	B								8	3MO							8		
Position	8	R	B				2/M	8											8		
MAIN 28VDC DISTRIBUTOR BUS DIFFERENTIAL PROTECTION RELAYS																					
Current	4	S	A								4	6MO							4		
Relay Trip	4	R	B				1/M	4											4		
MAIN 28 VDC DISTRIBUTOR BUS SECTIONALIZATING CB'S																					
Position	4	S	B								4	3MO							4		
Position	4	R	B				2/M	4											4		
MAIN 28 VDC DISTRIBUTOR BUS POWER SWITCHES																					
Position	28	S	B								28	3MO							28		
Position	28	R	B				2/M	28											28		
MAIN 28 VDC DISTRIBUTOR-BUS REVERSE CURRENT RELAYS																					Trip relay and switch (typical for all reverse-current relays)
Current	14	S	A								14	6MO							14		
Relay Trip	14	R	B				1/M	14											14		

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D-Day
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Table I-8

SUBSYSTEM: EPS (TCD) (Cont.)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
Measurement stimulus signal				Q	SI	SR	SR	Non Crit Q	Caution Q	Warning Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
MAIN 28 VDC DISTRIBUTOR BUS Voltage	4	R	A				6/M	4			4	1W					4	(2) 4/D	4		
28 VDC BUS TIE CABLE																					
Current	1	R	A								1	1W					1	(1) 4/H	1		
28 VDC BUS TIE CABLE CB'S																					
Position	8	S	B								8	3MO							8		
Position	8	R	B				2/M	8											8		
28 VDC FEEDERS TO DISTRIBUTION PANELS (LOAD BUSES)																					
Current	18	R	A								18	1W							18		
28 VDC DISTRIBUTION FEEDER CB'S																					
Position	36	S	B								36	3MO							36		
Position	36	R	B				2/M	36											36		
28 VDC LOAD BUSES																					
Voltage	12	R	A	12			1/S	12			12	1W					12	(1) 4/H	12		
28 VDC LOAD BUS SECTIONALIZING CB'S																					
Position	8	S	B								8	3MO							8		
Position	8	R	B				2/M	8											8		
260 VDC LINK BUS DIFFERENTIAL PROTECTION RELAYS																					
Current	2	S	A								2	6MO							2		
Relay Trip	2	R	B				1/M	2											2		
260 VDC LINK BUS CB'S																					
Position	12	S	B								12	3MO							12		
Position	12	R	B				2/M	2											12		
260 VDC LINK BUS POWER SWITCHES																					
Position	8	S	B								8	3MO							8		
Position	8	R	B				2/M	8											8		
260 VDC LINK BUS REVERSE CURRENT RELAYS																					
Current	4	S	A								4	6MO							4		

Q-Quantity
S-Stimulus
R-Response

A-Analog
B-Bilevel
D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

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H-Hour
D-Day
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Table I-8

SUBSYSTEM: EPS (TCD) (Cont.)	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Relay Trip	4	R	B				1/M	4											4		
260 VDC LINK BUS																					
Voltage	2	R	A				5/S		2		2	1W					2	(1) 4/H	2		
260 VDC BUS TIE CABLE																					
Current	1	R	A								1	1W							1		
260 VDC BUS TIE CABLE CB'S																					
Position	4	S	B								4	3MO							4		
Position	4	R	B				2/M	4											4		
MAIN 400 HZ DISTRIBUTOR BUS POWER SWITCHES																					
Position	16	S	B								16	3MO							16		
Position	16	R	B				2/M	16											16		
400 HZ SQUARE WAVE BUS TIE CABLE																					
Current	1	R	A								1	1W							1		
400 HZ SQUARE WAVE DISTRIBUTOR BUS																					
Voltage	6	R	A	6			5/S		6		6	1W					6	(1) 4/H	6		
400 HZ SQUARE WAVE BUS TIE CABLE CB'S																					
Position	8	S	B								8	3MO							8		
Position	8	R	B				2/M	8											8		
400 HZ SQUARE WAVE FEEDERS TO DISTRIBUTION PANELS																					
Current	36	R	A								36	1W							36		
400 HZ SQUARE DISTRIBUTION FEEDER CB'S																					
Position	24	S	B								24	3MO							24		
Position	24	R	B				2/M	24											24		
400 HZ SQUARE WAVE LOAD BUSES																					
Voltage	36	R	A				1/S	36			36	1W							36		
400 HZ SQ WAVE LOAD BUS SECTIONALIZING CB'S																					
Position	8	S	B								8	3MO							8		

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R-RF
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Table I-8

SUBSYSTEM: EPS (TCD) (Cont.) — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Position	8	R	B				2/M	8											8		
400 HZ SINE WAVE BUS TIE CABLE																					
Current	1	R	A								1	1W							1		
400 HZ SINE WAVE BUS TIE CABLE CB'S																					
Position	8	S	B								8	3MO							8		
Position	8	R	B				2/M	8											8		
400 HZ SINE WAVE FEEDERS TO DISTRIBUTION PANELS																					
Current	36	R	A								36	1W							36		
400 HZ SINE WAVE DISTRIBUTION FEEDER CB'S																					
Position	24	S	B								24	3MO							24		
Position	24	R	B				2/M	24											24		
400 HZ SINE WAVE LOAD BUS																					
Voltage	36	R	A				1/S	36			36	1W							36		
400 HZ SINE WAVE DISTRIBUTOR BUS																					
Voltage	6	R	A	6			5/S		6		6	1W					6	(1) 4/H	6		
400 HZ SINE WAVE LOAD BUS SECTIONALIZING CB'S																					
Position	8	S	B								8	3MO							8		
Position	8	R	B				2/M	8											8		
MAIN 60 HZ DISTRIBUTOR BUS POWER SWITCHES (SINGLE POLE)																					
Position	4	S	B								4	3MO							4		
Position	4	R	B				2/M	4											4		
60 HZ BUS TIE CABLE																					
Current	1	R	A								1	1W							1		
60 HZ BUS TIE CABLE CB'S																					
Position	4	S	B								4	3MO							4		
Position	4	R	B				2/M	4											4		

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R-Response

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Table I-8

SUBSYSTEM: EPS (TCD) Cont'd — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
60 HZ FEEDERS TO DISTRIBUTION PANELS																					
Current	2	R	A								2	1W							2		
60 HZ DISTRIBUTION FEEDER CB'S																					
Position	8	R	B				2/M	8											8		
60 HZ LOAD BUS																					
Voltage	2	R	A				6/M	2			2	1W							2		
600 HZ STARTING BUS CB'S																					
Position	12	S	B								12	1MO							12		
Position	12	R	B								12	1MO							12		
600HZ STARTING BUS																					
Voltage	6	R	A								6	1MO							6		
600 HZ TRANSMISSION CABLE TO ALTERNATOR NO. 1																					
Current	3	R	A								3	(3) 1MO							3		(3) Uses Load Bank
600 HZ TRANSMISSION CABLE TO ALTERNATOR NO. 2																					
Current	3	R	A								3	(3) 1MO							3		
600 HZ MOTOR GENERATORS																					
Motor Current	2	R	A								2	1MO							2		
Generator Current	6	R	A								6	(3) 1MO							6		
Generator Voltage	6	R	A								6	1MO							6		
Generator Frequency	2	R	A								2	1MO							2		
MOTOR GEN. NO. 1 OUTPUT CB																					
Position	2	S	B								2	1MO							2		
Position	2	R	B								2	1MO							2		
REGULATED TRANSFORMER RECTIFIER																					
Input Current	15	R	A								15	1MO							15		To check TR load sharing - redundant unit must be rotated on line to complete periodic check
Output Current	5	R	A								5	1MO					5	(1) 4/H	5		
Output Voltage	1	R	A								1	1MO							1		No load measurement of off line unit

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Table I-8

SUBSYSTEM: EPS (TCD) Cont'd — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Temperature	5	R	A				4/H	5			5	1MO					5	(2) 4/D	5		
Current Limiting	5	R	B				2/M	5											5		(One unit is standby)
Current Limiting (Test Current)	5	S	A								5	1MO							5		Inject overload test current into secondary of sensing circuit and monitor for current limit
HIGH VOLTAGE RECTIFIER REGULATOR																					
Input Current	12	R	A								12	1MO							12		To check rect load sharing - two redundant units must be rotated on line to complete periodic check
Output Current	4	R	A								4	1MO					4	(2) 4/D	4		
Output Voltage	4	R	A								4	1MO							4		No load measurement of off line units
Temperature	4	R	A				4/H	4			4	1MO					4	(2) 4/D	4		
Current Limiting	4	R	B				2/M	4											4		(Two units are standby)
Current Limiting (Test Current)	4	S	A								4	1MO							4		
400 HZ SQUARE WAVE INVERTER																					
Input Current	2	R	A								2	(3) 1W							2		Inverters do not operate in parallel
Output Current	6	R	A								6	1W							6		
Output Voltage	6	R	A								6	1W							6		
Frequency	2	R	A								2	1W							2		
Power Factor	6	R	A								6	1W							6		
Temperature	2	R	A				4/H	2			2	1W					2	(2) 4/D	2		
Current Limiting	2	R	B				2/M	2											2		(One unit is standby)
400 HZ SINE WAVE INVERTER																					
Input Current	2	R	A								2	1W							2		
Output Current	6	R	A								6	1W							6		
Output Voltage	6	R	A								6	1W							6		
Frequency	2	R	A								2	1W							2		
Power Factor	6	R	A								6	1W							6		
Temperature	2	R	A				4/H	2			2	1W					2	(2) 4/D	2		
Current Limiting	2	R	B				2/M	2											2		(One unit is standby)

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SI-Sampling Interval
SR-Sampling Rate

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Table I-8

SUBSYSTEM: EPS (TCD) Cont'd — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
60 HZ SINE WAVE INVERTER																					
Input Current	2	R	A								2	1W							2		
Output Current	2	R	A								2	(3) 1W							2		
Output Voltage	2	R	A								2	1W							2		
Frequency	2	R	A								2	1W							2		
Power Factor	2	R	A								2	1W							2		
Temperature	2	R	A				4/H	2			2	1W					2	(2) 4/D	2		
Current Limiting	2	R	B				2/M	2											2		(One unit is standby)
LAUNCH AND ASCENT/EMERGENCY INVERTER																					In standby during normal orbital operations
Input Current	2	R	A								2	(3) 1W							2		Check units in sequence
Output Current	6	R	A								6	1W							6		
Output Voltage	6	R	A								6	1W							6		
Frequency	2	R	A								2	1W							2		
Power Factor	6	R	A								6	1W							6		
Temperature	2	R	A				4/H	2											2		
Current Limiting	2	R	B				2/M	2											2		
BATTERY CHARGER REGULATORS																					
Input Current	10	R	A								10	1W							10		
Output Current	10	R	A								10	1W					10	(1) 4/H	10		
Output Voltage	10	R	A								10	1W							10		
Temperature	10	R	A								10	1W					10	(2) 4/D	10		
Current Limiting	10	R	B				2/M	10											10		
High Rate/Low Rate Mode	10	R	B								10	1W					10	(1) 4/H	10		
High Rate/Low Rate Mode	10	S	B								10	1W							10		
Current Limiting (Test Current)	10	S	A								10	1W							10		
BATTERY SWITCHING UNIT																					
Position	30	S	B								30								30		

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Table I-8

SUBSYSTEM: EPS (TCD) Cont'd

Measurement/stimulus signal	Quantity	Category (S,R)	Type (A,B,D,P,R)	Operation Q	Operation SI	Operation SR	Status Monitoring SR	Status Monitoring Non Crit Q	Status Monitoring Caution Q	Status Monitoring Warning Q	Periodic Checkout Q	Periodic Checkout SI	Periodic Checkout SR	Calibration Q	Calibration SR	Calibration SI	Trend Q	Trend SR	Fault Isolation Q	Fault Isolation SR	Remarks
Position	30	R	B								30								30		
BATTERY BUCK REGULATORS																					
Output Current	10	R	A								10	1MO							10		
Output Voltage	10	R	A								10	1MO							10		
Temperature	10	R	A				4/H	10			10	1MO					10	(2) 4/D	10		
Current Limiting	10	R	B				2/M	10											10		
Current Limiting (Test Current)	10	S	A								10	1MO							10		
MOTOR GENERATOR INPUT CB'S																					
Position	2	S	B								2	1MO							2		
Position	2	R	B								2	1MO							2		
LAUNCH AND ASCENT/EMERGENCY INVERTER INPUT CB'S																					
Position	2	S	B								2	1W							2		
Position	2	R	B								2	1W							2		
BATTERIES																					
Terminal Voltage	10	R	A	10													10	(2) 4/D	10		For trend analysis, switch batteries off line one at a time and measure open circuit voltage
Monitor Voltage	10	R	A	10							10	1W					10	(2) 4/D	10		
Current	10	R	A	10															10		
Temperature	10	R	A				4/H	10			10	1W					10	(1) 4/D	10		
POWER CONTROL MODULES (TBD)																					

Q–Quantity
S–Stimulus
R–Response

A–Analog
B–Bilevel
D–Digital

P–Pulse
R–RF
SI–Sampling Interval
SR–Sampling Rate

S–Second
M–Minute
H–Hour
D–Day
W–Week
MO–Month

Table I-9

DMS SUBSYSTEM

MEASUREMENTS/STIMULI	NUMBER OF SIGNALS	SIGNAL TYPE	SIGNAL CATEGORY	OPERATIONAL: CONTROL Q	CONTROL R	DISPLAY Q	DISPLAY R	CHECK OUT USAGE: FAULT DETECTION Q	FAULT DETECTION R	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT R	FAULT ISOLATION Q	FAULT ISOLATION R	TREND ANALYSIS Q	TREND ANALYSIS R	CALIBRATE Q	CALIBRATE R	CAUTION Q	CAUTION R	WARNING Q	WARNING R	REMARKS
Multiprocessor Group																						
CPU Power Supply Signal	6	B	R	-	-	-	-	6	(1)	-	-	6	(1)	-	-	-	-	(2)	(1)	-	-	(1) This signal is "Hard
Main Memory Power Supply Signal	12	B	R	-	-	-	-	12	TBD	-	-	12	TBD	-	-	-	-	-	-	-	-	Wired" into the CPU as an "Interrupt"
Aux Memory Power Supply Signal	30	B	R	-	-	-	-	30	TBD	-	-	30	TBD	-	-	-	-	-	-	-	-	Monitoring intervals do not apply
Switch Matrix Power Supply Signal	2	B	R	-	-	-	-	2	TBD	-	-	2	TBD	-	-	-	-	-	-	-	-	(2) If more than (TBD) signals
Multiprocessor Equip Rack Temp.	4	A	R	-	-	-	-	4	1/M	4	1/MO	4	1/S	4	1/3M	4	1/3MO	-	-	-	-	are received
Bulk Data Storage																						
Tape Transport Pwr Sup Signal	4	B	R	-	-	-	-	4	1/M	-	-	4	1/S	-	-	-	-	-	-	-	-	
Tape Controller Pwr Sup Signal	4	B	R	-	-	-	-	4	1/M	-	-	4	1/S	-	-	-	-	-	-	-	-	
Tape Electronics Pwr Sup Signal	2	B	R	-	-	-	-	2	1/M	-	-	2	1/S	-	-	-	-	-	-	-	-	
Data Acquisition																						
Digital Terminal Pwr Sup Signal	50	B	R	-	-	-	-	50	1/M	-	-	50	1/S	-	-	-	-	-	-	-	-	
Stim Gen. Unit Pwr Sup Signal	42	B	R	-	-	-	-	42	1/H	-	-	42	1/S	-	-	-	-	-	-	-	-	
Analog Interface Unit Pwr Sup Signal	4	B	R	-	-	-	-	4	1/M	-	-	4	1/S	-	-	-	-	-	-	-	-	
Data Bus Controller Pwr Sup Signal	4	B	R	-	-	-	-	4	TBD	-	-	4	TBD	-	-	-	-	-	-	-	-	
Data Bus Terminal Equip Rack Temp.	50	A	R	-	-	-	-	50	1/M	50	1/MO	50	1/S	50	1/3M	50	1/3MO	-	-	-	-	
Stimulus Gen. Unit Output Check Cmd	42	D	C	-	-	-	-	42	1/D	-	-	42	1/M	-	-	-	-	-	-	-	-	
Stimulus Gen. Unit Output Check Resp.	42	TBD	R	-	-	-	-	42	1/D	-	-	42	1/M	-	-	-	-	-	-	-	-	
Command Control & Display Consoles (2)																						
Microfilm Assy. Pwr Sup Signal	4	B	R	-	-	-	-	4	1/H	-	-	4	1/M	-	-	-	-	-	-	-	-	
Display Lamps Pwr Sup Signal	2	B	R	-	-	-	-	2	1/H	-	-	2	1/M	-	-	-	-	-	-	-	-	
Audio/Video Assys. Pwr Sup Signal	4	B	R	-	-	-	-	4	1/H	-	-	4	1/M	-	-	-	-	-	-	-	-	
General Console Pwr Sup Signal	4	B	R	-	-	-	-	4	1/H	-	-	4	1/M	-	-	-	-	-	-	-	-	
CCDC Equip. Rack Temp.	6	A	R	-	-	-	-	6	1/M	6	1/MO	6	1/S	6	1/3M	6	1/3MO					
Cmd. Buffer & Control Self Test Cmd.	2	D	C	-	-	-	-	2	1/D	-	-	2	1/S	-	-	-	-	-	-	-	-	

Table I-9

DMS SUBSYSTEM

MEASUREMENTS/STIMULI	NUMBER OF SIGNALS	SIGNAL TYPE	SIGNAL CATEGORY	OPERATIONAL: CONTROL Q	OPERATIONAL: CONTROL R	OPERATIONAL: DISPLAY Q	OPERATIONAL: DISPLAY R	CHECK OUT USAGE: FAULT DETECTION Q	FAULT DETECTION R	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT R	FAULT ISOLATION Q	FAULT ISOLATION R	TREND ANALYSIS Q	TREND ANALYSIS R	CALIBRATE Q	CALIBRATE R	CAUTION Q	CAUTION R	WARNING Q	WARNING R	REMARKS
Cmd. Buffer & Control Self Test Response	2	D	R	-	-	-	-	2	1/D	-	-	2	1/S	-	-	-	-	-	-	-	-	
SCU/CBC Output Check Command	2	D	C	-	-	-	-	2	1/D	-	-	2	1/S	-	-	-	-	-	-	-	-	Integrated CCDC Checkout Routine
SCU/CBC Output Check Response	2	D	R	-	-	-	-	2	1/D	-	-	2	1/S	-	-	-	-	-	-	-	-	
SCU Digital Feedback Check Command	2	D	C	-	-	-	-	2	1/D	-	-	2	1/D	-	-	-	-	-	-	-	-	
SCU Digital Feedback Check Response	2	D	R	-	-	-	-	2	1/D	-	-	2	1/D	-	-	-	-	-	-	-	-	
Image Processing																						
Film Scanner Pwr Sup Signal	1	B	R	-	-	-	-	1	1/H	-	-	1	1/M	-	-	-	-	-	-	-	-	
Image Digitizer Pwr Sup Signal	1	B	R	-	-	-	-	1	1/H	-	-	1	1/M	-	-	-	-	-	-	-	-	
Multi-Chn. Filter Pwr Sup Signal	1	B	R	-	-	-	-	1	1/H	-	-	1	1/M	-	-	-	-	-	-	-	-	
Perm. Analog Storage Pwr Sup Signal	2	B	R	-	-	-	-	2	1/H	-	-	2	1/M	-	-	-	-	-	-	-	-	
Perm. Digital Storage Pwr Sup Signal	2	B	R	-	-	-	-	2	1/H	-	-	2	1/M	-	-	-	-	-	-	-	-	
General Console Pwr Sup Signal	2	B	R	-	-	-	-	2	1/H	-	-	2	1/M	-	-	-	-	-	-	-	-	
Equipment Rack Temperature	2	A	R	-	-	-	-	2	1/M	2	1/MO	2	1/S	2	1/3M	2	1/3MO	-	-	-	-	
G,N&C Preprocessors (5)																						
Preprocessor Power Supply Signal	5	B	R	-	-	-	-	5	1/M	-	-	5	1/S	-	-	-	-	-	-	-	-	(1) During space station
Preprocessor Self Test Command	5	D	C	-	-	-	-	5	1/M (1)	-	-	5	1/S (3)	-	-	-	-	-	-	-	-	manuevering, rates may
Preprocessor Self Test Response	5	D	R	-	-	-	-	5	1/M (1)	-	-	5	1/S (3)	-	-	-	-	-	-	-	-	have to be increased to
																						1/TBD.

Appendix I-10A

SUBSYSTEM: EC/LS — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
				Q	SI	SR	SR	Non Crit Q	Caution Q	Warning Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
BRAYTON CYCLE EPS ONLY																					
Atmosphere Reconditioning																					
CO_2 Control																					
3 Way Valve Position	4	R	B								4	3MO							4		
Hot Circulating Fluid Temp	2	R	A								2	3MO							2		
Hot Circulating Fluid Flow	2	R	A								2	3MO	1/S						2	1/S	
Water Management																					
Urine Water Recovery																					
Heating Fluid Inlet Temp	2	R	A								2	3MO							2		
Bypass Valve Position	2	R	B								2	3MO							2		
Bypass Valve Sensor Response	2	R	A								2	3MO							2		
Bypass Valve Control	2	S	A								2	3MO							2		
Water Storage																					
Heating Water Inlet Temp	2	R	A								2	3MO							2		
Temperature Valve Sensor Output	10	R	A								10	3MO							10		
Waste Management																					
Fecal Waste Collection																					
Heating Water Inlet Temp	4	R	A								4	3MO							4		
Thermal Control																					
Heating Water Circuit																					
Water Flow Rate	2	R	A				1/S		2		2	3MO	1/S						2	1/S	
Pump Inlet Temperature	2	R	A								2	3MO							2		
Accumulator Pressure	2	R	A				1/S	2			2	3MO							2		

Q-Quantity
S-Stimulus
R-Response

A-Analog
B-Bilevel
D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
W-Week
MO-Month

Appendix I-10(a)

SUBSYSTEM: EC/LS	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
BRAYTON CYCLE EPS ONLY (Cont.)																					
Gas Separator Moisture	2	R	B				1/S	2			2	3MO							2		
Pump Performance	4	R	A								4	3MO							4		
Pump On Indication	4	R	B								4	3MO							4		
Heating Water Control																					
Water Outlet Temp	2	R	A				1/S		2		2	3MO							2		
Water Inlet Temp	4	R	A								4	3MO							4		
Pressure Relief Vlv Moisture	2	R	B				1/S	4			2	3MO							2		

Q-Quantity
S-Stimulus
R-Response

A-Analog
B-Bilevel
D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
W-Week
MO-Month

Appendix I-10(b)

SUBSYSTEM: EC/LS	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
SOLAR CELL EPS ONLY																					
Pressure Reconditioning																					
CO2 Control																					
CO_2 Temperature Sensor Signal	8	R	A								8	3MO							8		
Temperature Controller Perfor.	8	R	A								8	3MO							8		
Temperature Controller Control	8	S	A								8	3MO							8		
Water Management																					
Urine Water Recovery																					
Air Outlet Temp Signal	2	R	A								2	3MO							2		
Temperature Controller Perf.	2	R	A								2	3MO							2		
Temperature Controller Control	2	S	A								2	3MO							2		
Water Storage																					
Stored Water Temp. Signal	10	R	A								10	3MO							10		
Temperature Controller Perf.	10	R	A								10	3MO							10		
Temperature Controller Control	10	S	A								10	3MO							10		
Waste Management																					
Fecal Waste Collection																					
Container Temperature Signal	4	R	A								4	3MO							4		
Temperature Controller Perf.	4	R	A								4	3MO							4		
Temperature Controller Control	4	S	A								4	3MO							4		

Q-Quantity
S-Stimulus
R-Response

A-Analog
B-Bilevel
D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
W-Week
MO-Month

Appendix I-10(c)

SUBSYSTEM: STRUCTURES Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Additions (Solar Array Power Boom)																					
Support Boom Actuator Control	2	S	B	2	(1)														2		(1)Once per event (placing arrays in folded or unfolded position)
Support Boom Actuator Position - Folded	2	R	B	2	(1)														2		
Support Boom Actuator Position - Unfolded	2	R	B	2	(1)														2		
Support Boom Lock Control	2	S	B	2	(1)														2		
Support Boom Lock Position	2	R	B	2	(1)														2		
Turret Head (Y-Axis) Drive Unit Control	2	S	A								2	3MO							2		
Turret Head (Y-Axis) Drive Unit Power Monitor	2	R	A								2	8H							2		
Turret Head (X-Axis) Position	2	R	A								2	3MO							2		
Y/? Axis Drive Unit Control	2	S	A								2	3MO							2		
Y/? Axis Drive Unit Power Monitor	2	R	A								2	8H							2		
Y/? Axis Torque Shaft Position	2	R	A								2	3MO							2		
Inflatable Seal Pressure Control	2	S	B								2	3MO							2		
Inflatable Seal Pressure Monitor	2	R	A								2	3MO	1/S						2	1/S	
Power Boom Module Pressure Control	1	S	A								1	3MO							1		
Power Boom Module Pressure Monitor	1	R	A								1	3MO	1/S						1	1/S	
Power Boom Module Temperature Monitor	2	R	A								2	3MO	1/S						2	1/S	
Deletions																					
Isotope Power System HDLG & REPL Equip.																					
Drive Unit Power Monitor	2	R	A																2		

Q-Quantity
S-Stimulus
R-Response

A-Analog
B-Bilevel
D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
W-Week
MO-Month

Appendix I-11

SUBSYSTEM: EPS-TCD Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Inverter (Core & Boom)																					
Output Voltage	24	R	A								24	1MO							24		
Output Current	24	R	A				6/M	12			24	1MO							24		
Power Output (3 Φ)	8	R	A				6/M	8			8	1MO					8	(1) 4/H	8		(1) To generate short term profile; retain data for two weeks
Frequency	8	R	A				6/M	8			8	1MO							8		
Synch Signal	8	R	D				6/M	8			8	1MO							8		Used for wave form generation and in synchronizing outputs
Temperature	8	R	A				4/H	8			8	1MO					8	(2) 4/D	8		(2) Check against previous weeks data) retain previous two weeks data
Module Switching	36	S	B								36	1MO							36		Power match switching for efficiency (boom=4x6=24 modules;core=4x3=12 modules)
Inverter Feeder Contactor (Boom)																					
Position	8	S	B								8	3MO							8		
Position	8	R	B				5/S		4										8		
Inverter Feeder																					
Current	12	R	A				6/M	12			12	1W					12	(1) 4/H	12		
Inverter Feeder Differential Protection																					
Current	12	S	A								12	6MO							12		
Trip	12	R	B				1/S	12											12		
Primary Bus																					
Voltage	12	R	A				1/S	12									12	(1) 4/H	12		
Primary Bus Differential Protection																					
Current	12	S	A								12	6MO							12		
Trip	12	R	B				1/S	12											12		
Primary Bus Tie Cables																					Assume bus tie cables included in primary bus differential protection zone
Current	12	R	A				6/M	12									12	(1) 4/H	12		
Primary Bus Tie Cable Contactors																					
Position	8	S	B								8	3MO							8		
Position	8	R	B				2/M	8											8		

Q-Quantity, S-Stimulus, R-Response
A-Analog, B-Bilevel, D-Digital
P-Pulse, R-RF, SI-Sampling Interval, SR-Sampling Rate
S-Second, M-Minute, H-Hour, D-Day, W-Week, MO-Month

Appendix I-11

SUBSYSTEM: EPS-TCD Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Boom Inverter Input Contactor																					Contactors not shown in Nar data; but function is implicit
Position	8	S	B								8	3MO							8		
Position	8	R	B				5/S		4										8		
Battery Charger Input Contactor																					
Position	24	S	B								24	3MO							24		
Position	24	R	B				1/S	24											24		
Battery Charger																					
On-Off Control	12	S	B								12	1W							12		
Recondition	12	S	B								12	1W							12		
Charge	12	S	B								12	1W							12		
On-Off Indication	12	R	B				1/S	12			12	1W							12		
Charge Time	12	R	A								12	1W							12		
Temperature	12	R	A				4/H	12			12	1W					12	(2) 4/D	12		
Input Power (3 Φ)	12	R	A								12	1W							12		
Input Current	36	R	A								36	1W							36		
Output Pulses	12	R	P								12	1W	(3)						12		(3) Assume symmetrical pulse train; sample for one minute at 20KHZ (use OCS ancillary equipment.)
Module Switching	12X TBD	S	B								12X TBD	1W							12X TBD		Power match switching for efficiency assume x=6 for this study
Core Inverter Input and Output Contactors																					
Position	16	S	B								16	3MO							16		
Position	16	R	B				1/S		8										16		
Auto Transformer Differential Protection																					
Current	12	S	A								12	6MO							12		
Trip	12	R	B				1/S	12											12		
Auto Transformer Input Contactor																					
Position	8	S	B																8		
Position	8	R	B				5/S		4										8		

Q-Quantity
S-Stimulus
R-Response

A-Analog
B-Bilevel
D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
W-Week
MO-Month

Appendix I-11

SUBSYSTEM: EPS-TCD — Measurement/stimulus signal	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,R)	OPERATION Q	OPERATION SI	OPERATION SR	STATUS MONITORING SR	STATUS MONITORING Non Crit Q	STATUS MONITORING Caution Q	STATUS MONITORING Warning Q	PERIODIC CHECKOUT Q	PERIODIC CHECKOUT SI	PERIODIC CHECKOUT SR	CALIBRATION Q	CALIBRATION SR	CALIBRATION SI	TREND Q	TREND SR	FAULT ISOLATION Q	FAULT ISOLATION SR	REMARKS
Autotransformer																					
Temperature	4	R	A				4/H	4			4	1MO					4	(2) 4/D	4		
Input Current	12	R	A								12	1MO							12		
Output Current	24	R	A								24	1MO							24		
Differential Current	12	R	A				1/S	12											12		
Secondary Bus Structure																					
Coolant Temperature In	4	R	A				4/H	4			4	1MO					4	(2) 4/D	4		
Coolant Temperature Out	4	R	A				4/H	4			4	1MO					4	(2) 4/D	4		
DC Bus Voltage	4	R	A				1/S	4			4	1MO					4	(1) 4/H	4		
AC Bus Voltage	12	R	A				1/S	12			12	1MO					12	(2) 4/H	12		
Secondary Bus Differential Protection (4 DC Buses, 4 AC Buses)																					
Current	16	S	A								16	6MO							16		
Trip	16	R	B				1/M	16											16		
Secondary Bus Contactors (Rect-Filter Input, AC Bus Input)																					Contactors not shown in Nar data, but function is implicit
Position	16	S	B								16	3MO							16		
Position	16	R	B				2/M	16											16		
60 HZ 115 Vac Single Phase Inverter (For GPL Loads)																					Two inverters-one is redundant
Output Voltage	6	R	A				6/M	6			6	1W							6		
Output Current	6	R	A				6/M	6			6	1W							6		
Frequency	2	R	A				6/M	2			2	1W							2		
Temperature	2	R	A				4/H	2			2	1W					2	(2) 4/D	2		
Rectifier-Filter																					
Temperature	4	R	A				4/H	4			4	1MO					4	(2) 4/D	4		
Input Voltage	12	R	A								12	1MO					12	(1) 4/H	12		
Output Current	4	R	A								4	1MO					4	(1) 4/H	4		
Solid-State Circuit Breakers																					
Position	(4) 1140	S	B								100	3MO							1140		(4)Comparable estimates not made for Isotope/Brayton configuration
Position	(4) 1140	R	B				2/M	1140											1140		
Reset	570	S	B								50	3MO							570		

Q-Quantity
S-Stimulus
R-Response

A-Analog
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D-Digital

P-Pulse
R-RF
SI-Sampling Interval
SR-Sampling Rate

S-Second
M-Minute
H-Hour
D-Day
W-Week
MO-Month

Appendix I-12

SUBSYSTEM: EPS-SOLAR ARRAY/BATTERY	QUANTITY	CATEGORY (S,R)	TYPE (A,B,D,P,K)	OPERATION			STATUS MONITORING				PERIODIC CHECKOUT			CALIBRATION			TREND		FAULT ISOLATION		REMARKS
								Non Crit	Caution	Warning											
Measurement/stimulus signal				Q	SI	SR	SR	Q	Q	Q	Q	SI	SR	Q	SR	SI	Q	SR	Q	SR	
Batteries																					
Cell Voltage	900	R	A				1/S	900											900		
Cell Temperature	900	R	A				4/H	900											900		
Cell Pressure	900	R	A				1/S	900											900		
Cell Bypass Control	900	S	B								900	1MO							900		Cell bypassed in event of cell failure
Cell Bypass Indication	900	R	B								900	1MO							900		
Cell Recondition Signal	900	S	B								36	1W							900		Periodic reconditioning of off line cells
Cell State of Charge	900	R	A				1/S	900											900		
Battery Voltage	12	R	A				1/M	12									12	(1) 4/D	12		(1)Check against previous week's data;retain initial and previous two weeks data
Battery Current	12	R	A				1/M	12											12		
Battery Coolant Temperature In	12	R	A				4/H	12											12		
Battery Coolant Temperature Out	12	R	A				4/H	12											12		
Battery On-Off Indication	12	R	B								12	1W							12		
Battery Control	12	S	B								12	1W							12		
Battery Failure	12	R	B				1/S		12										12		Caution generated by DMS following detection of > 3 cell failures/battery
Bi-Stem Actuator																					
Motor Control	4	S	B	4	(2)														4		(2)Used only for extension and retraction of panels
Motor Voltage	4	R	A																4		
Motor Current	4	R	A																4		
Array																					
Blanket Temperature	48	R	A				1/M	48											48		
Total Panel Current	4	R	A				1/M	4											4		
Panel Extended Length	4	R	A	4	(2)						4	1D							4		
Boom Tip Defection	4	R	A				1/M	4											4		
Circuit Voltage (V)	160	R	A								160	1D					160	(3)	160		(3)Circuit I-V characteristics transmitted to ground for trend analysis-sample once/orbit
Circuit Current (J)	160	R	A								160	1D					160	(3)	160		For first week, once/day for first year, and once/week for remainder of mission
Sun Position	8	R	A	8		1/S													8		
Sun Loss Indication	4	R	B	4		1/S													4		

Q-Quantity, S-Stimulus, R-Response
A-Analog, B-Bilevel, D-Digital
P-Pulse, R-RF, SI-Sampling Interval, SR-Sampling Rate
S-Second, M-Minute, H-Hour, D-Day, W-Week, MO-Month

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