

SEPTEMBER 1970  
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MDC G0492A

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ASTRONAUT/COMPUTER  
COMMUNICATION STUDY

Phase A Task 2 Report

**MCDONNELL DOUGLAS AERONAUTICS COMPANY**



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# **ASTRONAUT/COMPUTER COMMUNICATION STUDY**

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**SEPTEMBER 1970  
REVISED**

**MDC G0492A**

## **Contract NAS 825701 Phase A Task 2 Report**

Prepared for the National  
Aeronautics and Space Administration  
Huntsville, Alabama under  
Contract NAS8-25701

## PREFACE

This report documents the results of Phase A, Task 2 of the Astronaut/Computer Communication Study. It was prepared in compliance with the requirements of the Contract NAS8-25701. This document supercedes MDC G0492 dated September 1970. This issue (MDC G0492A dated September 1970) has been revised to reflect the latest available data.

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Section 1

Section 1  
INTRODUCTION AND SUMMARY

The primary objectives of Phase A of the Astronaut/Computer Communication Study are to identify and establish on-board functions in which the crew can utilize the on-board computer in performance of their assigned tasks and to define methods by which this communication can be accomplished. Phase A of this study consists of three tasks:

Task 1: Document crew/computer (on-board) communication methods on existing and near-term space vehicles.

Task 2: Establish crew functions to be performed with an on-board computer for Space Station and Space Shuttle. Define the extent to which the crew will participate in these functions.

Task 3: Devise methods by which the crew can communicate with the on-board computer to perform the functions determined in Task 2 with special emphasis upon the software and hardware required to support these functions.

Task 1 was completed May 1, 1970, and was documented in McDonnell Douglas Astronautics Company - West Report Number MDC G0388, dated May 1970. Task 2 is documented herein, and Task 3 will be completed October 18, 1970.

The purpose of Task 2 is to establish a list of crew functions to be performed on-board future spacecraft and to identify the areas where the on-board computer can assist in performing these functions. This task is only concerned with interactive functions (i.e., those functions in which the crewman utilizes the on-board computer in performing a task).

Task 2 is the critical task of this contract as it establishes a base for the remainder of the study. The ultimate purpose of this study is to define a

structured vocabulary and establish methods by which space scientists and astronauts can communicate (in performing on-board functions) with the on-board computer.

In determining on-board crew function requirements for future spacecraft, an assumption was made that future spacecraft would be as autonomous as state-of-the-art technology would permit. Ground support functions performed for Gemini and Apollo missions were considered as on-board function requirements for future spacecraft. To compile a composite list of spacecraft functions an in-depth analysis was conducted into the following areas:

- Ground support functions required by existing and past spacecraft and space missions.
- On-board functions required by existing and past spacecraft.
- Proposed functions for future spacecraft (Skylab, Space Shuttle, and Space Station).

Although much of the advanced system concepts were found in future manned space requirements, a high percentage of supporting data was obtained from the aircraft industry. The aircraft industry has more on-going projects than does the spacecraft industry, and has a more definitive automation direction. A review of the automation direction being followed by aircraft manufacturers provided a point of departure or a building block for developing mechanized spacecraft functions.

A careful investigation of current methods of documenting or listings on-board functions of both aircraft and spacecraft disclosed that several techniques were used. The more conventional methods were oriented toward mission timeline, mission phase or vehicle hardware subsystems. These techniques were generally voluminous in nature and redundant in content and therefore unsatisfactory for the purpose of this study.

As previously mentioned, the ultimate objective of the study is to define a structured vocabulary and establish methods by which space scientists or astronauts can communicate with the on-board computer. In identifying



the on-board function by technology or disciplines, a structure is thus established and a direct function, method and vocabulary relationship defined. It is for this purpose that the technique of grouping related functions into categories was adopted.

The nine function categories listed below have been established as a result of the analyses conducted as Task 2, of this study.

#### FUNCTION CATEGORIES AND DEFINITIONS

MISSION CONTROL - Functions required to monitor and evaluate actual versus planned mission data, and to adjust mission plan or correct vehicle performance as required to achieve desired mission goals.

DATA MANAGEMENT - Functions required to acquire, process, store, maintain and retrieve data as required to support the vehicle and related mission functions.

COMMUNICATIONS - Functions required to select the desired communications media (i.e., radio, T.V., radar, etc.) and related frequency/channel, antenna, and route of communications.

FLIGHT CONTROL - Functions required to maintain vehicle attitude and trajectory as required by the flight plan.

GUIDANCE AND NAVIGATION - Functions required to acquire and reduce G&N data so that the vehicle's current versus planned position and trajectory can be determined and the degree of deviation and compensating control functions can be computed.

EXPERIMENTS - Functions required to perform, monitor, and control experiments being performed from space vehicle.

MANEUVER MANAGEMENT - Functions required to initiate, execute, and evaluate success of a vehicle maneuver.

OPERATIONAL STATUS - Functions required to monitor and maintain vehicle and crew operational status.

MISSION INDEPENDENT CREW FUNCTIONS - Functions required to maintain crew proficiency and efficiency during long space missions.

These categories have been defined in terms of functions and detail sub-functions (Appendix A) to a level that Task 3 can logically devise methods and techniques for crew/computer interaction. As an example, a proposed

Space Station Astronomy Experiment shows the versatility of using function categories. The breakdown of this experiment shows the inter-relationship of functions and how methods, languages, and commands are derived. Typical experiment operation is discussed in Appendix B.

The results of this task support the philosophy that each function category will have its own interactive hardware and language requirements. This is not unreasonable to expect when considering that individual ground disciplines have unique computer/communication requirements and that future space language will, by necessity, have to be easy to learn and easy to use. After a thorough review of the Syntax compiler development, i.e., the McDonnell Douglas Syntax Directed Compiler, This requirement does not appear to be impractical or unreasonable. Future space missions will probably find the on-board computer user performing his job functions using a language and tools that are normally associated with his job function and/or discipline.

Note: Syntax compiler is defined as a computer software system which provides a means for defining Syntax in terms of a computer's "machine language." The defined Syntax can then be used to communicate problem requirements with the computer. The output of the McDonnell Douglas Syntax Directed Compiler can be used to recognize and analyze statements written in the defined language.

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**Section 2**

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## Section 2

### CURRENT ON-BOARD INTERACTIVE FUNCTIONS

In determining current on-board crew interactive functions, study analysis was limited to the Gemini and Apollo spacecraft, and selected aircraft. (As stated in Task 1 documentation, the scope of this study was expanded to include selected aircraft due to the limited number of historical and current manned spacecraft programs.) The evolution of interactive computer systems for aerospace vehicles has been slow with aerodynamics vehicles setting the pace. This is due in part to the lack of stringent weight constraints placed on aircraft and to the more rapid development of aircraft. Where spacecrafts have been limited to the minimum and proven capabilities, aircrafts have had the luxury of extensive field testing. This section will treat current aerospace applications of on-board interactive computer systems as being indicative of the capability which exist today for manned spacecraft.

#### 2.1 SPACECRAFT INTERACTIVE FUNCTIONS

Since the Gemini and Apollo space programs are the only manned programs to utilize an on-board crew/computer interactive communication system, all current on-board interactive functions will be derived from them. (A detailed analysis is being conducted on Russian spacecraft and a summary of this study will be included in the final Phase A report.) The Gemini and Apollo systems provided their respective crews with the following capabilities:

- Loading data into the computer
- Modifying data already in the computer
- Querying for data status
- Initiating commands to the vehicle subsystems.

Gemini, was more dependent on crew control of vehicle guidance and maneuver functions than Apollo.

### 2.1.1 Gemini

Although Gemini vehicles were equipped with interactive computer systems, the man-in-the-loop was an integral part of the vehicle's flight control system. The computer system was capable of automatic control of the boost and reentry phases of the mission, but once the space vehicle had achieved earth orbit, it was the responsibility of the crew to control the vehicle until reentry. During earth orbit, the crew controlled the space vehicle by obtaining course correction data from the computer and/or vehicle instrumentation. (Verification of on-board generated data was made by Mission Control on the ground).

Earth orbit control of the Gemini vehicle involved use of hand operated translation and rotation controls. The crew, after interpreting flight control data from the ground, and/or on-board computer, and/or vehicle instrumentation, could initiate analog impulses directly to vehicle subsystems to implement a vehicle's attitude or trajectory change. The on-board computer would then update internal ephemeris data by interpreting attitude changes from subsystem sensor inputs.

Using the on-board computer, the Gemini crew was able to perform or obtain assistance in performing one or more functions in the categories listed below:

- Flight Control
- Guidance and Navigation
- Data Management
- Communications
- Maneuver Management
- Operational Status
- Mission Independent Crew Functions

The primary purpose of the on-board computer was to perform flight control, guidance and navigation functions with other functions being secondary and considerably more limited in scope and capability.

### 2.1.2 Apollo

The crew/computer interactive capability on Apollo is similar to that of the Gemini but has more capability. This is the prime reason for selecting Apollo as a model for this study in identifying current on-board crew interactive functions for spacecraft. Apollo provides a firm, operational base of current capability by which to measure and expand as required, proposed functions for future space vehicles. Just as with Gemini, the primary purpose of Apollo's command module digital computer is to support the vehicle flight control, and guidance and navigation functions. Unlike the Gemini, normal control of the Apollo vehicle is through the on-board computer. Only as the result of a major control system failure will direct guidance commands go the Reaction Control System jets and to the Service Propulsion System engines.

The Apollo command module digital computer houses a highly mechanized system. Crewmen have the capability of: (1) loading data, (2) updating data, (3) querying for data status, and (4) initiating commands to the various vehicle subsystems via the computer. One of the primary functions of the crew is to monitor the automatic equipment and act as system backup in case of failure. The interactive capability afforded Apollo crewmen is similar to that of the Gemini, but Apollo has additional hardware capability and a more natural language with which to communicate (i.e., Gemini utilized a numeric coded command language and Apollo utilized an encoded English language noun/verb interface).

The interactive crew/computer functions available to Apollo crewmen are discussed below by function as defined in Appendix A.

Flight Control - Apollo crew members have three methods of performing flight control functions excluding the completely automatic and ground support capabilities.

The crew must perform these functions any time a "non-computerized" maneuver is required. To assist the reader in visualizing crew control of these

functions, a brief discussion of the three interactive methods available to the crew follows:

1. Conversational - Apollo crewmen via a display and keyboard (DSKY) were capable of commanding vehicle controls through the vehicle on-board computer. This method required use of the verb/noun crew/computer communication language developed for Apollo mission. This technique is described in detail in the Phase A Task 1 report (McDonnell Douglas Astronautics Company's report No. MDC-G0388, dated May, 1970).
2. Manual - The manual method of controlling Apollo in-flight maneuvers involved the hand operated translation, rotation and minimum impulse controls. By manipulating these controls, the Apollo crew could cause impulses to be sensed by the on-board computer. The computer would then interpret the impulses and generate control commands for execution by the Reaction Control System (RCS) jets and the Service Propulsion System (SPS) engines as required.
3. Direct - The direct method of communication with RCS jets and the SPS engines is similar to the manual method. The direct method utilized the hand operated controls but impulses bypass the on-board computer and go directly to the systems affected. This method is used only during major system failures.

The crew, if required, could completely control the following functions:

- Engine positioning
- Engine start time
- Thrust
- Engine stop time
- Vehicle attitude (roll, pitch, yaw)

Guidance and Navigation (G&N) - Guidance and navigation functions for the purpose of this study are calculation and determination of vehicle position, attitude, velocity, destination and flight path (trajectory) required to achieve mission destination. The control and directing functions sometimes associated with G&N, are considered as flight control. Under normal conditions, Apollo G&N functions, are capable of being performed automatically or under ground supervision, but the astronaut can perform the following functions:

- Command the computer to perform G&N functions

- Select computer programs to be executed
- Provide data to computer programs
- Make coarse optical sighting of celestial and ground land marks for computer use in G&N computations (uses on-board telescope)
- Make fine optical sighting of celestial and ground land marks for computer use in G&N computations (use on-board sextant)
- Direct computer to take optical readings from position of telescope and/or sextant
- Determine required vehicle attitude needed to make necessary optical sightings

Data Management - Data management functions performed on the Apollo vehicle are limited due to the hardware limitations which exist on-board. Functions are performed in the areas of data acquisition, storage and retrieval, but on "active-data", only. "Active-data" is defined as the data waiting to be executed by the computer system or the data waiting to be transmitted to the ground. Other data which is retrievable is generally changing in nature but static in location. The astronauts do have the capability of retrieving, modifying, and inserting data in these changing data fields. Some message formatting is performed for transmission ease to ground.

Communication - Most Apollo space vehicle communication functions are pre-programmed and controlled from the ground. One function which can be controlled by the crew and that is positioning of the high gain S-Band antenna. The astronaut can, by use of the verb/noun computer communication languages, initiate commands to alter the position of the S-Band antenna. Actual transmitting and receiving functions are controlled by the Ground and are limited by the capability of the ground station.

Maneuver Management - Vehicle maneuver functions by definition interface very closely with the flight control, G&N, data management, and operational status categories of functions. These interface requirements contributed, strongly, to the decision to make vehicle maneuvers a unique category. Extensive preparation is required before executing an intricate maneuver with the Apollo space vehicle. Maneuver preparation in some cases is similar to a dry-run or a dress rehearsal. The interactive functions required of the crew to



prepare and execute a maneuver exercises the on-board computer system extensively. This constitutes an on-board interactive capability. Some of the functions required are:

- Verify operational status of vehicle
- Verify availability of resources
- Verify crew physical and mental condition
- Update ephemeris data with ground data
- Initiate sequence to perform maneuver
- Monitor maneuver progress
- Verify maneuver has been completed successfully

Operational Status - Operational status functions on the Apollo vehicle are primarily performed to verify the vehicle's ability to achieve the predefined mission objectives. Many of these functions are performed automatically by the on-board computer, but the crew has the capability of inquiring and verifying status when required. Apollo fault determination, resulting from a negative status report usually results in executing the desired functions using an alternate method, rather than correcting the fault. Sometimes functions cannot be performed at all, as was the case with the color T. V. camera on Apollo 12. Some of the on-board operational status interactive functions performed during Apollo missions follow:

- Subsystem operating capability verification
- Computer system self test
- Fault detection
- Limited fault isolation
- Crew physical condition
- Cabin temperature and pressure monitoring
- Resource monitoring
- Cabin atmosphere monitoring

Mission Independent Crew Functions - Apollo mission independent crew functions did not require any crew/computer interactive functions as will be included in future spacecraft mission timelines. This can be attributed to the shortness

in duration of the mission. The purpose of mentioning this function category is to acknowledge the requirement for this type of function on board future space vehicles. Spacecraft crew members do perform functions related to exercise, entertainment and relaxation.

## 2.2 AIRCRAFT INTERACTIVE FUNCTIONS

The intent of this section is to identify the direction in which aircraft on-board "computerization" is taking. No specific aircraft will be discussed in this section; although, the F-15, F-111D, C-5A, and AWACS aircraft were analyzed with respect to this study.

Aircraft manufacturers are continually improving existing applications of on-board computer (such as G&N, on-board checkout, and weapons delivery) and are experimenting and developing new applications for the on-board computer. Some of these technology advances involve use of interactive cathode ray tube (CRT) devices, projected map displays, head up displays (HUD), and matrix displays. This new and more refined hardware is used to assist aircraft flight control, mission control, and data management functions. A brief examination and discussion of crew/computer interactive functions required by the increased mechanization of aircraft functions is presented below:

Operational Status - Technical advances have been made in the field of on-board checkout. Aircraft are now flying with an on-board, in-flight capability which permits the crew to:

- Detect faults
- Isolate faults
- Correct faults
- Avoid faults
- Verify fault correction
- Record faults and status of the vehicle

In-flight execution of these functions reduces the amount of ground maintenance time required and increases the flight readiness time of the vehicle.

Flight Control - Although aircraft flight control systems are becoming more sophisticated, one always sees conventional equipment in the cockpit. This is due to human nature; man's resistance to change. However, behind much of this equipment is an on-board computer performing many of the apparently manual functions. There is a trend, although slow, to replace much of the conventional equipment with specialized and general purpose CRT display and keyboard input devices. Thus eliminating the need for many of the gauges, switches, meters, and registers currently associated with aircraft. Electronic attitude direction indicators and automatic landing aids are also being developed. The development of this equipment increases interface requirements of crew/computer communication.

Guidance and Navigation - G&N functions have been expedited and improved by the introduction of on-board computers and interfacing projected map displays and electronic attitude direction indicators. These devices provide a more accurate and timely method for performing G&N functions and implementing mission planning changes. The crew via these devices supplies data directly to the computer which performs the G&N computations to generate decision making data. Crew interfaces are, in general, limited to button pushing, switch setting, and some keyboard data inputs.

Mission Control - With the increase in aircraft "computerization," mission control functions are becoming an on-board requirement. Usually, an aircraft takes off with a predefined mission/destination and flight path, and any in-flight changes cause problems in generating a new flight plan (i.e., emergency landing fields, fuel requirements, etc.). Now, with technology advances, the pilot is being given such on-board capability that soon he will be in a position to implement instantaneous flight plan changes.

Communication - Probably some of the biggest gains in on-board crew/computer interaction are being made with respect to communication. With today's technology an in-flight crewman can request the computer to: (1) project on a CRT, the ground stations within range of contact, (2) select the contact station, and (3) automatically have the on-board equipment aligned to the selected station. A rippling effect is indicated as a ground station goes

out of range and the next is automatically selected and tuned. This function can be performed automatically.

Data Management - With all of the increased computer functions being performed on board aircraft today and planned for future aircraft, data management is becoming a significant problem. Much progress has been made in this area with the advent of lighter equipment which can house more processing capability and storage capacity. Aircraft crewmen now have the capability of retrieving, storing and changing current and/or historical data depending on function requirement.

### 2.3 SUMMARY

In summary current aircraft and spacecraft crewmen are capable of interfacing with the on-board computer as follows:

- Loading data into the computer
- Modifying data already in the computer
- Querying for data status
- Initiating commands to vehicle subsystems

The crew/computer interactive capability for the Gemini, Apollo, and space vehicles currently under development is identified in the following matrices for each of the function categories established and defined during this study. Although this list includes all function categories established during the study, it is not intended for the reader to assume that the named function categories have been fully developed. There is need for much additional work to identify and develop total interactive computer capability for an autonomous space vehicle.

SPACE PROGRAM INTERACTIVE FUNCTION CAPABILITY

MISSION CONTROL

Functions	Gemini	Apollo	Skylab	Space Shuttle	Space Station
Planning	No On-Board Planning	No On-Board Planning	Limited to Experiments		
Timeline Event Analysis	--	--	X	X	X
Timeline Event Scheduling	--	--	X	X	X
Monitoring					
Mission Performance	N/A	N/A	N/A	X	X
Vehicle Sub-system Status	Limited	Limited	Limited	X	X
Resource Utilization Rate	Limited	Limited	Limited	X	X
Commanding					
Continue Planning Mission	Fixed	Fixed	X	X	X
Alter Planned Mission	Fixed Abort or Alternate	Fixed Abort or Alternate	Abort via Return Vehicle	X	X

DATA MANAGEMENT

Functions	Gemini	Apollo	Skylab	Space Shuttle	Space Station
Acquisition					
Identification					
Tagging	N/A	N/A	Limited	X	X
Cataloging	N/A	N/A	Limited	X	X
Assimilation					
Grouping	X	X	X	X	X
Formatting	X	X	X	X	X
Modification					
Calibration					
Scaling	Ground Based	Ground Based	Limited	X	X
Biasing	Ground Based	Ground Based	Limited	X	X
Improvement	N/A	N/A	Advanced Models		
Filtration	--	--	Limited	X	X
Integration	--	--	Limited	X	X
Correlation	--	--	Limited	X	X
Storage & Retrieval					
Location	Fixed	Fixed	Advanced Models		
Interrogation	--	--	Limited	X	X
Scan	--	--	Limited	X	X
Extraction	Fixed	Fixed	Limited	X	X
Fetch	Limited	Fixed	Advanced Models	X	X
Assignment					
Temporary	X	X	X	X	X
Permanent	None	None	Advanced Models	X	X
Purge	Update	Update	Limited	X	X

COMMUNICATIONS

Functions	Gemini	Apollo	Skylab	Space Shuttle	Space Station
Transmission					
Message Formatting	Limited	Limited	X	X	X
Hardware Selection	Fixed	Limited	Limited	X	X
Message Routing	Fixed	Fixed	X	X	X
Reception					
Message Acquisition	Fixed	Limited	X	X	X
Hardware Alignment	Fixed	Limited	Limited	X	X
Message Verification	Limited	Limited	Limited	X	X

FLIGHT CONTROL

Functions	Gemini	Apollo	Skylab	Space Shuttle	Space Station
Trajectory Flight Path Analysis	N/A	N/A	Fixed Orbit		
Course Change Analysis	--	--	Attitude Only	X	X
Resource Availability	--	--	Limited	X	X
Trajectory Change Implementation					
Change Sequencing	Fixed	Fixed	X	X	X
Initiate Control Function Sequence	Limited	Limited	--	X	X
Trajectory Change Evaluation			N/A		
Change Performance Monitoring	Limited	Limited	--	X	X
New Trajectory Determination	Limited	Limited	--	X	X



GUIDANCE AND NAVIGATION (G&N)

Functions	Gemini	Apollo	Skylab	Space Shuttle	Space Station
G&N Measurement Determination					
Inertial Measurements	X	X	X	X	X
Active Range & Range Rate Measurements	X	X	X	X	X
Optical Measurements	None	X	X	X	X
G&N Data Reduction Computation					
Define Reference Trajectory	Limited	Limited	Limited	X	X
Define Trajectory Deviation	X	X	X (Orbit Only)	X	X
Compute Required Controls	X	X	Attitude Only	X	X

MANEUVER MANAGEMENT

Functions	Gemini*	Apollo	Skylab**	Space Shuttle	Space Station***
Preparation			N/A		Limited Requirement
Checklist	Highly Manual	Highly Manual	--	X	X
System Initialization	Limited	X	--	X	X
Execution			N/A		Limited Requirement
Identify & Schedule Maneuver Events	--	--	--	X	X
Initiate Sequence of Events	Manual	Limited	--	X	X
Monitor Maneuver Progress	X	X	--	X	X
Evaluation			N/A		
Checklist Interpretation	Manual	Manual	--	X	X
Position Change Review	Limited	Limited	--	X	X

\*Gemini was a manual system except for ascent and descent - a manual descent capability did exist.

\*\*Skylab will have a fixed orbit mission only requiring attitude changes.

\*\*\*Space Station will have a limited maneuvering capability which future tugging requirements will also be required to control free fly modules.

OPERATIONAL STATUS

Functions	Gemini	Apollo	Skylab	Space Shuttle	Space Station
<b>Crew</b>					
Life Support	Ground Based	Ground Based	Limited	X	X
Environmental Control	Limited	Limited	Limited	X	X
<b>Vehicle</b>					
On-Board Checkout	Fault Detection	Fault Detection	Limited	Ground Based	X
Electrical	Fixed	Fixed	Limited	X	X

EXPERIMENTS

Functions	Gemini	Apollo	Skylab	Space Shuttle	Space Station
<b>Initiate</b>					
Plan	N/A	Fixed	Fixed	N/A	X
Preparation	N/A	Manual	Limited	N/A	X
<b>Execute</b>					
Monitor	N/A	N/A	X	N/A	X
Control Real Time	N/A	N/A	Limited	N/A	X
<b>Terminate</b>					
Secure	N/A	N/A	Limited	N/A	X
Document	N/A	N/A	Limited	N/A	X
Evaluate	N/A	N/A	Ground Based	N/A	X

MISSION INDEPENDENT CREW FUNCTIONS

Functions	Gemini	Apollo	Skylab	Space Shuttle	Space Station
Training					
Maintain Skills Level	--	--	Limited	No Requirement Initially	X
Develop New Skills	--	--	--	No Requirement Initially	X
Recreation					
Entertainment	--	Limited	X	Limited Initially	X
Exercise	--	Limited	X	Same	X
Relaxation	Limited	Limited	X	Same	X

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**Section 3**

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## Section 3

### EXPANDED FUNCTIONS PROPOSED FOR FUTURE SPACE VEHICLES

To expand current on-board crew/computer interactive functions an analysis of the proposed on-board requirements for Skylab, Space Shuttle, and Space Station was conducted. The functions identified during the analysis are indicative of the on-board crew function requirements for manned space missions through the mid 1980's. This statement is based on spacecraft development schedules, and the variation in mission requirements of the space programs analyzed.

#### 3.1 SKYLAB

Skylab is being developed as an experimental space station for the purpose of conducting experiments in space. The majority of experiments to be performed on-board Skylab fall into the following four categories:

- Investigation of the space environment and related phenomena
- Application for future space missions
- Effects of long duration space flights on crew and system
- Economic consideration for future manned space flights

The Skylab orbital cluster will be a Saturn Workshop (SWS) with an Apollo command service module (CSM) docked to it.

An analysis of Skylab on-board function requirements revealed:

- (1) The CSM to be used for Skylab is essentially the same vehicle used for Apollo lunar missions, and the on-board crew functions required by the Apollo CSM will be applicable to the Skylab CSM. For this reason readers are referred to Section 2, Paragraph 2.1.2.

- (2) The major expansion of current on-board function capability requirements is in space experiments.

The computer found in SWS module of Skylab is referred to as the Apollo telescope mount digital computer (ATMDC). This subsystem is composed of two computers. One is in an active mode. The other remains in an "idle" or monitoring mode. The major functions to be performed by the activated computer are:

- Attitude control
- Experiment assistance

Attitude control becomes critical when performing solar experiments involving the on-board telescope. Due to the limitations of telescope movement capability and the effect of this movement on the vehicle, it is easier to move the vehicle than the telescope.

The number of functions that must be performed by the crew in support of on-board experiments, maintenance and personnel requirements makes the computer a valuable tool. The computer can assist in preparation, execution and progress monitoring of on-board experiments, e.g., the ATMDC can be used to determine position requirements for the telescope, course and fine align the telescope, monitor the activity of the celestial phenomena being observed and signal the space scientist when abnormal conditions arise (i.e., observed object disappears from line of sight, etc.).

### 3.2 SPACE SHUTTLE

A study of Space Shuttle on-board requirements concluded that function categories already defined could absorb the new function requirements imposed by this project (reference Appendix A). Consideration was given to a unique category for the aerodynamic functions performed by the Shuttle booster and orbiter (ascent or reentry). Exo-atmospheric to atmospheric transition is accomplished through an autopilot technique. The hand control for the Reaction Control jets which are set in an automatic mode are shut off

mechanically at a specified atmospheric altitude. The vehicle then glides into the atmosphere under an autopilot system controlling the aerodynamic surfaces. This maneuver is performed under complete control of the space pilot. The decision not to separate these functions was made because of the similarity with functions performed in space, and to the additional requirements which would be imposed on the flight crew. The Shuttle vehicle increases on-board function requirements, over those already established, in the categories of operational status, mission control, flight control, maneuver management, guidance and navigation.

The following discussion will be oriented toward the orbiter with the assumption that booster functions overlap and in most cases on-board functions are applicable to both vehicles.

Operational Status - One of the design criteria for Space Shuttle is that it must be a reusable space vehicle. To minimize the flight preparation time normally required by ground crews and to insure inflight vehicle operational capability, the Space Shuttle programs require an automatic and crew interactive on-board checkout system. Specific functions involve rapid fault detection, isolation and correction techniques. Faults have to be isolated to the line replaceable unit (LRU) level in order to make rapid corrections.

Mission Control - The Shuttle orbiter is being proposed with "on-board autonomy" capabilities. In order to be autonomous, mission planning and control functions must be performed on-board. This involves altering or modifying the original mission which requires major interfaces with the on-board computer system and data bases. An example is a change in landing condition due to adverse weather condition.

Flight Control - Current plans are to have total computer interface the vehicle subsystems and continuous evaluation of flight control functions. The crew may operate with conventional equipment, such as a yoke, pedals, switches, etc., but impulses will be interpreted and commands issued by the on-board computer. Space Shuttle will also require aerodynamic flight control functions (this is the case during ascent and landing).



Maneuver Management - Additional vehicle maneuvers for Space Shuttle are being established all of which will involve crew interaction (i.e., landing, docking with cargo, aerodynamic maneuvers as well as space, tugging (possibility). Crew interaction will involve defining required "non-computerized" maneuvers and manual execution of the maneuver (this occurs with deviations in predefined flight plans).

Guidance and Navigation - Capabilities on-board Shuttle will permit the crew to obtain navigation data, reduce it, and make G&N decisions without ground verification. This imposes additional crew G&N function, but goes along with the theme of vehicle autonomy.

Data management and communication requirements will be enhancement over current on-board function capabilities, but will not exceed current state-of-the-art capability.

### 3.3 SPACE STATION

The proposed Space Station will be similar to Skylab. Major differences will be in vehicle size, versatility, and mission duration. The Space Station will interface with the Space Shuttle like the Skylab interfaces with the Apollo Command and Service Module (CSM), but unlike the Skylab the Space Station will not require a docked Shuttle for the duration of a mission.

Space Station crew interactive functions which are expansions of current on-board function requirements are primarily in space experimentation, mission crew independent functions, data management, and operational status function categories.

Space Experimentation - Probably the most important function of the Space Station mission is to perform experiments. Space scientists will rely heavily on the on-board computer for assistance. The computer will provide the capability of monitoring and controlling the progress of the experiment,

and collecting data for future review and reporting. The computer will also provide a useful calculating and simulating tool for use by the space scientists in determining the direction of the experiment being performed.

Mission Independent Crew Functions - This category of functions is very important on Space Stations where crewmen will be required to spend long periods of time confined on a Space Station. The computer will maintain a history of crew exercise and rest periods to insure each crewman maintains his physical condition. The computer will also assist in training and maintaining a skills level for the Space Station and the individual crewmen. Maintaining a skills level will be in the form of computer testing and job simulation. Job simulation will exercise infrequent job functions required by a particular job.

Operational Status - Due to the long duration of Space Station missions, a major requirement will be to maintain the crew and vehicle in operating condition. The on-board computer will be a very important tool in performing this type of function. The computer will be capable of initiating stimuli for the various subsystems for use in fault isolation and collection. It will provide continuous monitoring of operating subsystems and detect marginal functioning line replaceable units (LRU's). This will be particularly useful in avoiding subsystem failures.

Computerized medical tools will be on-board for the purpose of determining crew physical fitness and health requirements. A mental health detector capability is being proposed to ascertain crew alertness and mental awareness. Other life support and environmental control problems to be performed by the computer are:

- Sense and maintain cabin temperature and pressure
- Sense and maintain cabin atmosphere
- Inventory consumables food, air, water, etc.
- Assist with waste management

Section 4

## Section 4

### CREW REQUIREMENTS IN PERFORMING ON-BOARD FUNCTIONS

This section discusses crew requirements in performing the on-board functions identified by the studies documented in sections two and three of this report. A total of nine function categories have been established and the degree of crew/computer interaction will vary according to the specific category. This section will discuss crew responsibilities in performing each function category. These categories are defined and discussed in detail (i.e., function and subfunction composition) in Appendix A.

Specific methods for crew/computer interaction in performing the required functions will not be discussed in the report but will be included in the Phase A, Task 3 and Final report. Methods that are implied or mentioned in this section are for the purpose of describing the crew/computer interaction and crew participating requirements.

#### 4.1 MISSION CONTROL FUNCTIONS

Mission control involves the decisions which must be made concerning the future of a space mission, and involves mission monitoring, planning, and commanding. During a manned space mission the on-board computer continually monitors mission critical functions and displays for the flight commander that data which he needs to determine mission performance and progress. In performing his in-flight monitoring the flight commander will also have the capability to query the status of vehicle subsystems, resource utilization rates (consumables and expendables) and performance factors developed by the computer to convey actual performance versus planned. Should the flight commander be required to make a change to the mission plan, he can retrieve from the on-board computer the current performance capability of the vehicle (i.e., what events are planned, which ones must be completed, and what unused capability remains). He can then indicate an event to be performed and/or time and

conditions that an event is to be performed. The computer can then schedule the event allocating resources and resolving any conflicts. The computer will also determine the impact of the mission timeline changes on the remainder of the mission and display this data for consideration by the flight commander. After determination and scheduling of a mission timeline change, the commander can via the on-board computer issue commands to initiate the event timeline change. This will result in the computer automatically allocating resources, dedicating subsystem capability and implementing the event.

#### 4.2 DATA MANAGEMENT FUNCTIONS

Data management functions are imposed by the large volumes of data being required by manned space missions of the future, and the associated on-board computer capability needed to access, store, and retrieve data. This function is one-hundred percent computer performed, and can be thought of as a sophisticated input/output control system. The data management system will do the input/output "bookkeeping" for the applications and systems software programs executed by the on-board computer.

#### 4.3 COMMUNICATION FUNCTIONS

Crew participation in performing communication functions will be primarily conversational with a minimum hardware selection requirement (i.e., switch settings, hardware alignment, etc.). Most space communications will be performed with computer predefined stations. Once a station is selected by the crew the computer will automatically select and align the hardware. Should contact with a non-defined station be required the crew will have the capability of selecting the hardware and aligning the system via a conversational language with the computer. There will also be automatic communications capability on-board for uplink and downlink telemetry exchanges.

#### 4.4 FLIGHT CONTROL FUNCTIONS

Flight control functions are similar to mission control functions except flight control is more concerned with the immediate situation of the

vehicle. The on-board flight controller maintains an awareness of the in-flight vehicle and crew safety status by monitoring flight critical data projected on the display devices by the on-board computer. Upon detection of improper data reading(s), the flight controller can determine the extent and solution to the problem by performing an in depth analysis using the on-board computer. Once the problem solution has been determined, the flight controller can implement a flight change by controlling the flight control functions being executed by the on-board computer. He will continually monitor and evaluate the progress of initiated flight control functions to assure proper execution of the function. All flight control functions are performed via the on-board computer under the direction of the flight controller.

#### 4.5 GUIDANCE AND NAVIGATION FUNCTIONS

An autonomous guidance and navigation (G&N) system will be a requirement for future manned space vehicles. A completely automatic data acquisition system will reside on-board and supply data to the on-board computer for reduction and subsequent updating of G&N data parameters. The on-board crew will be capable of overriding automatically generated G&N value and inquiring as to the current vehicle trajectory. As a backup the crew can manually take optical and inertial data readings to supply the G&N system for computation. The G&N system can be utilized in a conversational mode to determine current trajectory deviation over planned and course correction requirements.

#### 4.6 EXPERIMENT FUNCTIONS

Crew participation in performing on-board experiments will vary from experiment to experiment, but in general space scientists will be equipped with a conversational command language for use in communicating function requirements with the on-board computer. Via this language and interfacing experiment hardware, they will be able to determine experiment status and control the progress and direction of the experiment. They will also be capable of entering discrettes from his experiment control panel for interpretation and execution by the computer. After completion of an experiment the computer

will provide a useful tool in analyzing and evaluating experiment results, and assisting with experiment reporting.

#### 4.7 MANEUVER MANAGEMENT FUNCTIONS

Before performing a vehicle maneuver, the crew performs an extensive check of the vehicle's operating capability using the on-board computer based on the sequence of events to be executed. This involves verifying the ephemeris data existing in the computer, initializing systems, determining availability of resources, and verification of event timing. Once the operating capability of the vehicle is established the maneuvers can be executed. This phase of the man-machine interface is anticipated to be performed with conventional equipment (i.e., in the case of Space Shuttle yoke, rudders, switches, etc.). The actual commands will be generated by the computer. During and after execution of the desired maneuver, the computer system will be interrogated to evaluate the degree of success of the maneuver.

#### 4.8 OPERATIONAL STATUS FUNCTIONS

Operational status functions are the more obvious ones required for future manned space missions, and therefore, the more publicized. These functions entail maintaining vehicle and crew in operating condition. The on-board computer plays a vital role in performing these functions. The computer continually monitors the vehicle operating and crew safety subsystems, and provides a highly conversational interactive language in performing operational status functions. Language characteristics permit detailed inquiry into the operating status of a subsystem for the purpose of determining operating status and isolating faults.

#### 4.9 MISSION INDEPENDENT CREW FUNCTIONS

In performing mission independent crew functions the on-board computer is going to be an important factor in maintaining crew skills. The crew via a conversational language and interactive control panels will be required to practice their job functions while the computer simulates the job being

performed. In this manner crewmen will maintain proficiency in job functions which they are seldom required to perform. Similarly the computer will provide a self instruction course for crewmen in developing new skills in different disciplines. Other mission independent crew functions (i.e., crew entertainment, relaxation and exercise) will require very little computer interaction during the immediate manned space program, but as the manned space effort evolved, there will be a need for computer generated entertainment, crew relaxation requirement and cycle tracking, and crew exercise requirements and cycle tracking.



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Appendix A

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## Appendix A

### FUNCTION CATEGORY DESCRIPTIONS AND BREAKDOWN

The intent of this appendix is to define and discuss the function categories defined as Task 2 Phase A of this study. These categories were defined after analyzing on-board function requirements for spacecraft and aircraft, and grouping related functions for ease in studying crew/computer interactive communication requirements.

After completing an analysis of current and proposed on-board function requirements for future manned space missions, nine categories of functions have been identified and defined. Many of these categories were obtained from current requirements, and future manned space efforts only enhanced the number of required functions to be performed in a category. Other categories are applicable only to future manned space missions.

#### A.1 MISSION CONTROL (Figure A-1)

The functions considered in this category are the mission planning, monitoring, and commanding ground support functions performed for past manned space missions. In order to attain a high degree of vehicle autonomy, the responsibility for making mission control decisions must reside on-board.

An initial preflight mission plan, including a detailed mission timeline, will be made on the ground with the assistance of ground support agency, but after launch, contingency planning and timeline adjustment capability must be capable of being performed on-board the inflight vehicles. Timeline updates involve:

- Analysis of the events to be performed for the remainder of the mission;
- The effect of these events on the remainder of the mission;

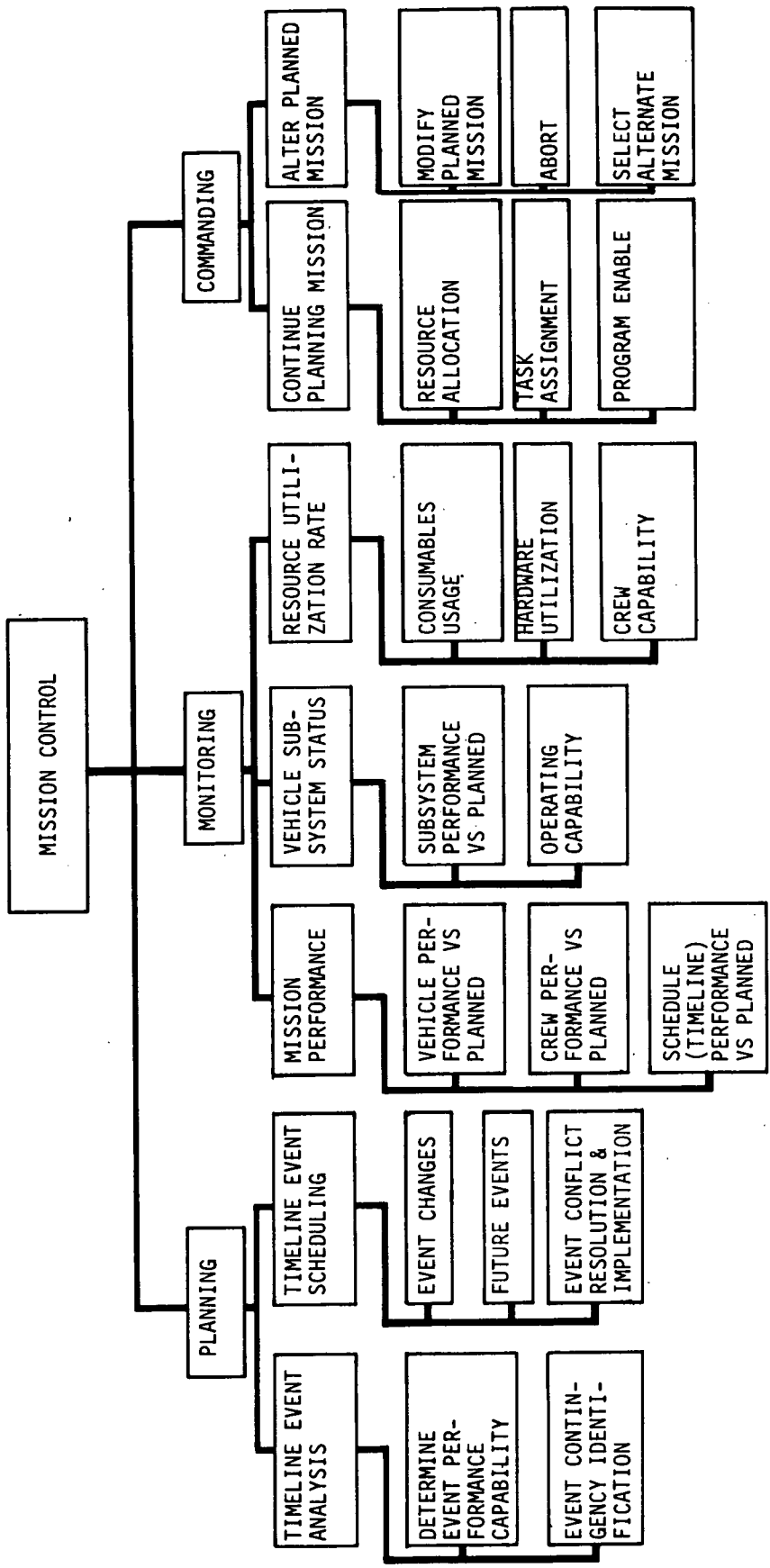


Figure A-1 MISSION CONTROL FUNCTION BREAKDOWN

- The scheduling of new events or adjustment of events already scheduled;
- Event conflict identification and resolution imposed by timing constraints, resource requirements, vehicle subsystems utilization, etc.

Planning - Two types of planning are required for manned space mission, preflight and inflight. Preflight planning will be accomplished with ground support equipment. This study is concerned with inflight planning imposed by a change in mission plans based on extenuating circumstances. When a mission has to be changed, the on-board capability must be available for detecting and resolving event schedule conflicts, so that total scheduling can be accomplished. There is also a need for reanalysis of scheduled events performance and reschedule of events which have not been performed due to unanticipated problems.

Monitoring - The monitoring of mission control functions ensures that the mission is progressing as planned, or in the event a marginal operating state is detected, ample time will be available for corrective action.

Primarily on-board mission monitoring will be concerned with monitoring the mission itself (timeline event execution versus actuals), vehicle status (vehicle subsystem performance and operating capability versus planned), and resource utilization versus planned.

Command - Command functions are those which initiate action after mission monitoring and planning have been performed. Decision and commanding functions will be initiated for execution of vehicle control functions and crew task assignments.

As changes are incorporated through the command procedure, a continuation of planning and resource allocation will continue. New task assignment and alternate mission planning functions will be the criteria used during execution of the command function. Complete software program enable, disable and mission abort will be included in the command procedure profile.

## A.2 DATA MANAGEMENT (Figure A-2)

The functions in the data management category are computer oriented. Data management will deal with the acquisition, storage and retrieval, and on-board modification of data. It will be the responsibility of the executing application program to modify and display the data as expected by the user. Data management can be considered as an automatic filing system. It will have the capability of acquiring data randomly, identifying the data, grouping the data and storing the data for future use. This system will also retain storage information for the purpose of retrieving it upon command for use by an applications program. This system will allow for various data manipulations such as scaling, biasing, calibration, noise filtration, integration, and correlation.

## A.3 COMMUNICATIONS (Figure A-3)

Communication category functions to be performed on-board a manned spacecraft, either internal or external, have been divided into two major functions, transmission and reception. The interactive function for transmitting will be concerned with message formatting, hardware selection and initialization, and message routing.

Data formatting will include compression techniques to transmit the least amount of data and maintain the highest degree of significance. Compression techniques will be of the class of 4:1 and will not encompass validation operations described under data management.

Message routing is concerned with getting a message to the proper addressee (person, facility, etc.). This may require relay routing via a free flying module, other space vehicle or remote tracking station, or direct routing to the addressee. Receiving data will require hardware alignment with the sending station, message acquisition and verification of data received.

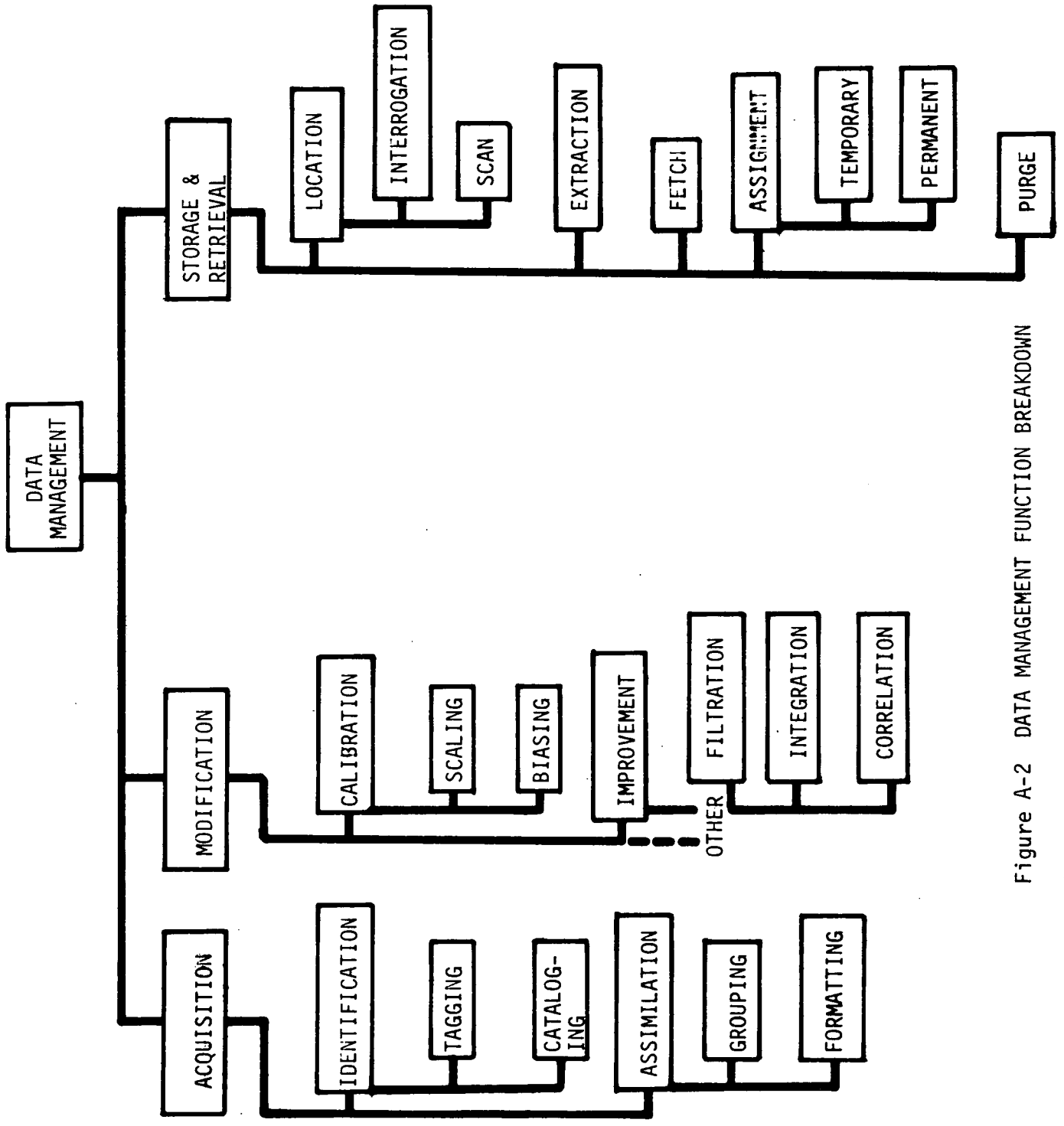


Figure A-2 DATA MANAGEMENT FUNCTION BREAKDOWN

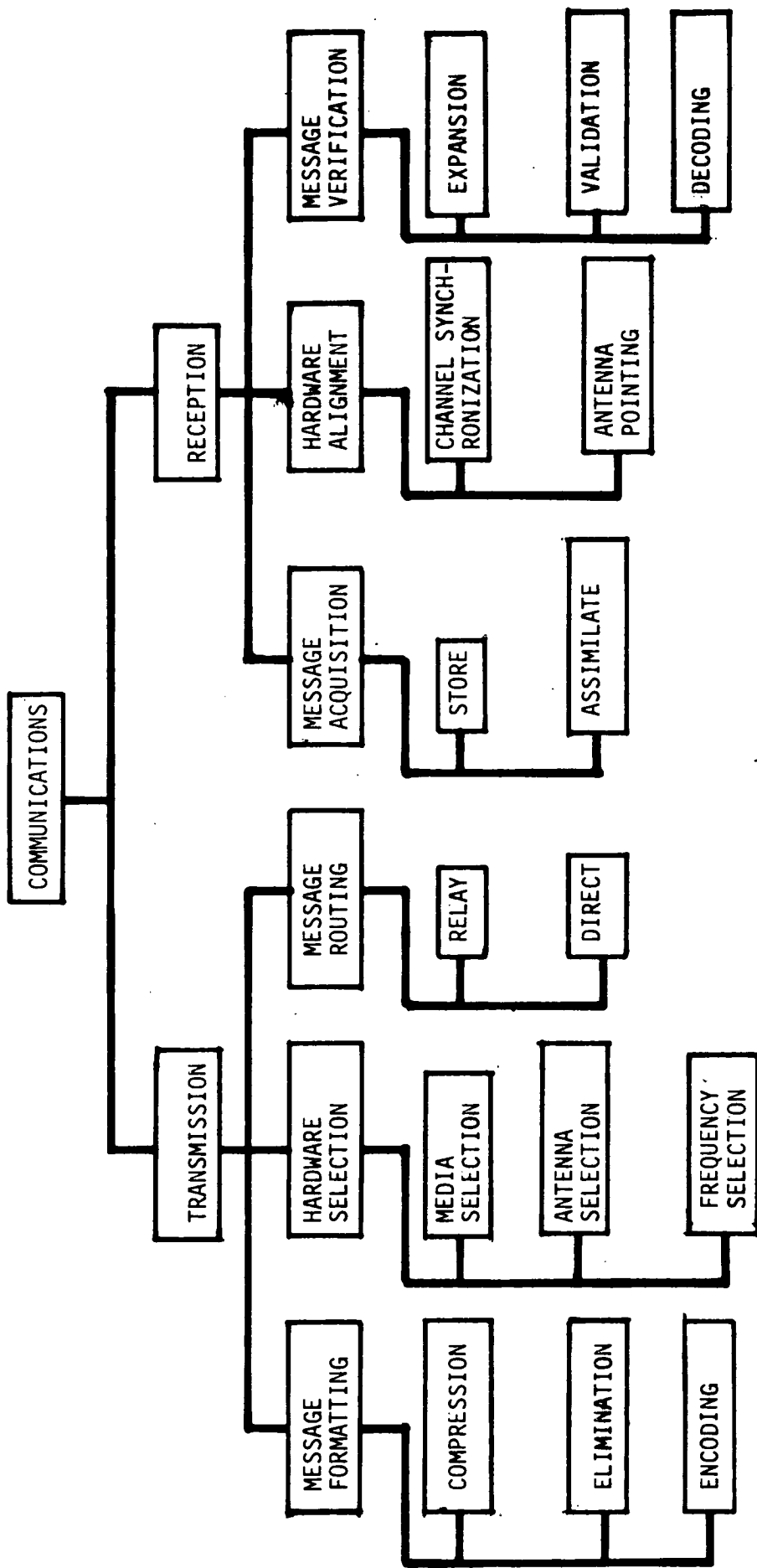


Figure A-3 COMMUNICATIONS FUNCTION BREAKDOWN

Upon receiving data that has been compressed, expansion of this data will become a function requiring crew and computer analysis and control. A verification or validation task will be performed to determine data significance.

#### A.4 FLIGHT CONTROL (Figure A-4)

The flight control category is concerned with immediate trajectory problems and crew safety functions that must be considered in achieving mission destination. This category is subdivided into three major functions: trajectory flight path analysis, trajectory change implementation, and trajectory change evaluation.

Trajectory/Flight Path Analysis - Trajectory/flight path analysis subfunctions involve continuous analysis of the vehicle's trajectory so that deviation from the planned trajectory can be detected quickly and corrective action initiated. After detection of a trajectory error a more intensive analysis commences in determining correction requirements (i.e., maneuver, type, etc.), and the optimum time and location at which corrective action can be taken. Consideration must be given to events in process and scheduled, and to subsystem and resource requirements.

Trajectory Change Implementation - After trajectory analysis has been completed and a corrective maneuver has been determined, flight control must implement this corrective action. Sequencing and scheduling of event required to attain the desired trajectory must be accomplished, and the subsystems and resources which will be utilized by the events must be allocated. After establishing this criteria the event sequence execution can be initiated.



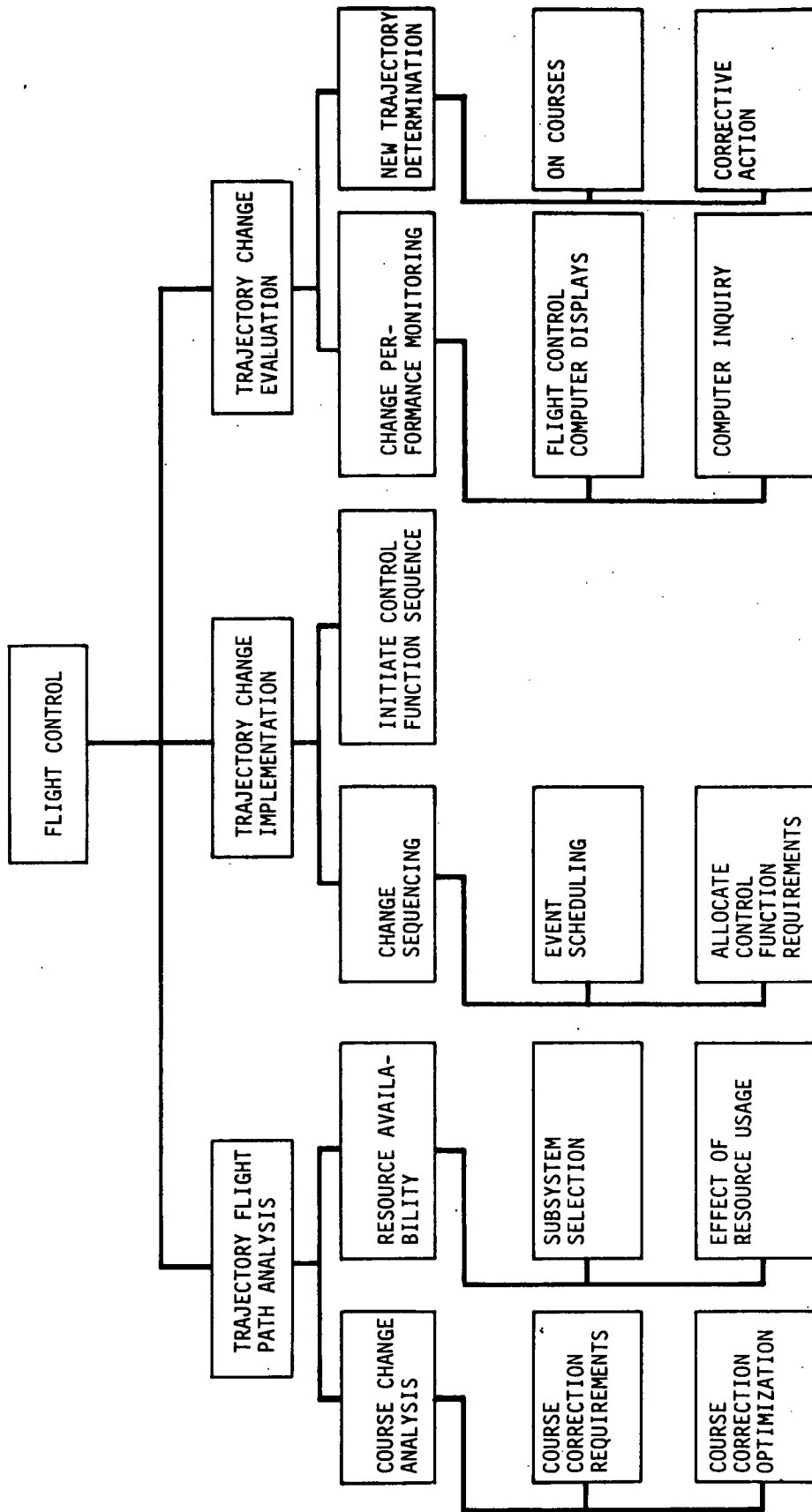


Figure A-4 FLIGHT CONTROL FUNCTION BREAKDOWN

Trajectory Change and Evaluation - During and after the implementation of a trajectory change, evaluations are made to determine maneuver success. If the vehicle does not achieve the desired trajectory, the reason must be determined, corrected, and a new sequence of control functions executed.

#### A.5 GUIDANCE AND NAVIGATION (Figure A-5)

The guidance and navigation category is subdivided into two functions: G&N measurement determination and G&N data reduction computations. These two functions produce data required in performing both flight control and maneuvering functions.

G&N Measurement Determination - The subfunctions of this function are concerned with the acquisition of G&N data. The data is obtained from the on-board measurement devices and identifies the vehicle's position, velocity, acceleration, time and attitude. These subfunctions are concerned with the acquisition of measurement data obtained from inertial units from vehicle motion, range determination units, and optical measurement units. Analysis of measurement data will allow the crew to make decisions as to the validity of various guidance determinations. The crew can then input changes directly into guidance or navigation equation constants.

Optical measurement subfunctions include recording celestial position for updating navigation data. The crew will then determine gross trajectory error.

G&N Data Reduction Computations - Regardless of the source of G&N measurement data, vehicle or ground, data reduction functions are performed to define the vehicle's reference trajectory. Comparing the computed trajectory against the desired trajectory, a trajectory deviation can be computed. Using equation of motion and guidance laws, the control function to be executed to achieve the desired trajectory can be computed.

#### A.6 EXPERIMENTS (Figure A-6)

The on-board experiments scheduled for the Skylab and Space Station cover a broad spectrum of applications. Even though a major difference exists between

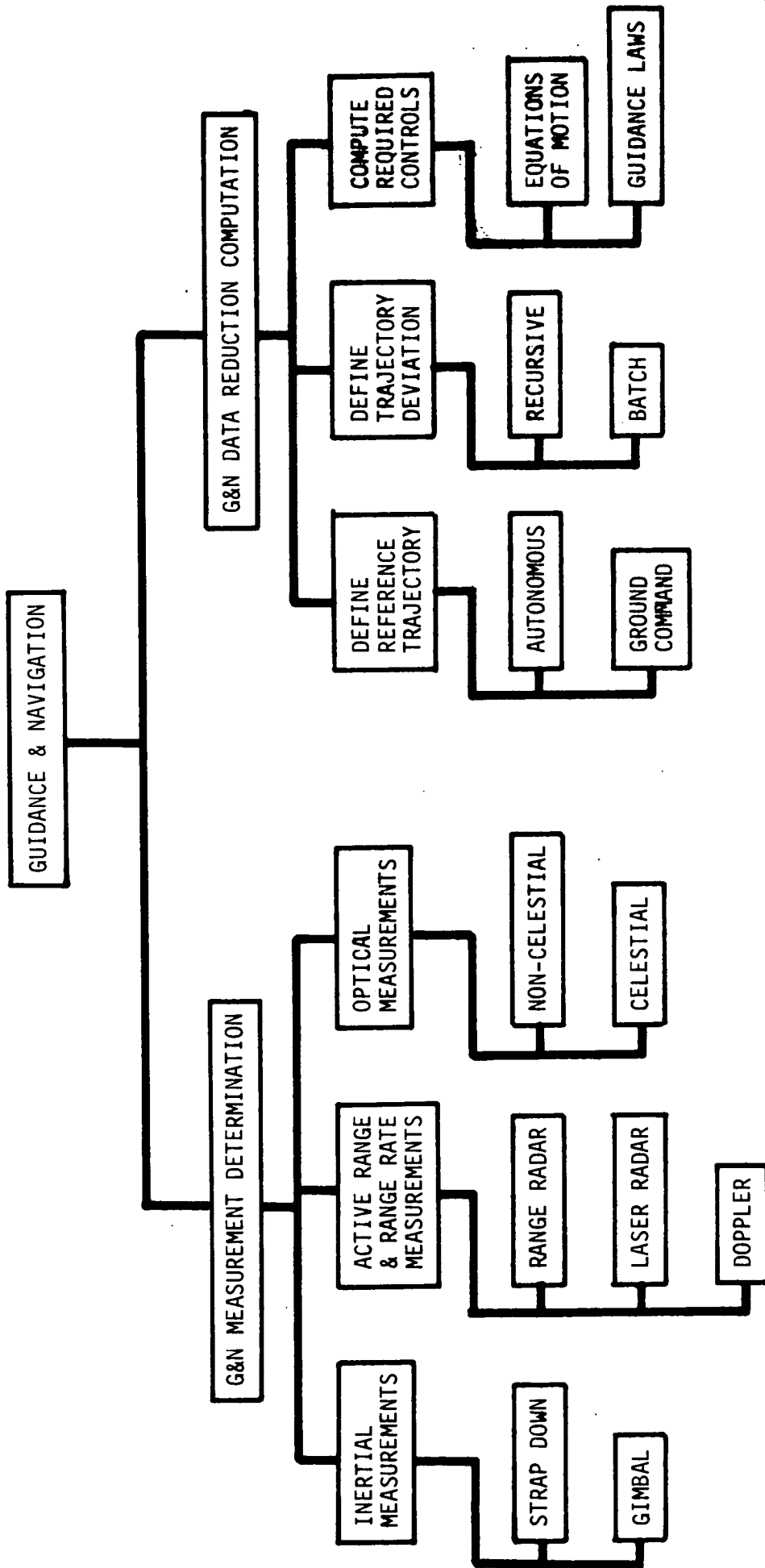


Figure A-5 GUIDANCE AND NAVIGATION FUNCTION BREAKDOWN

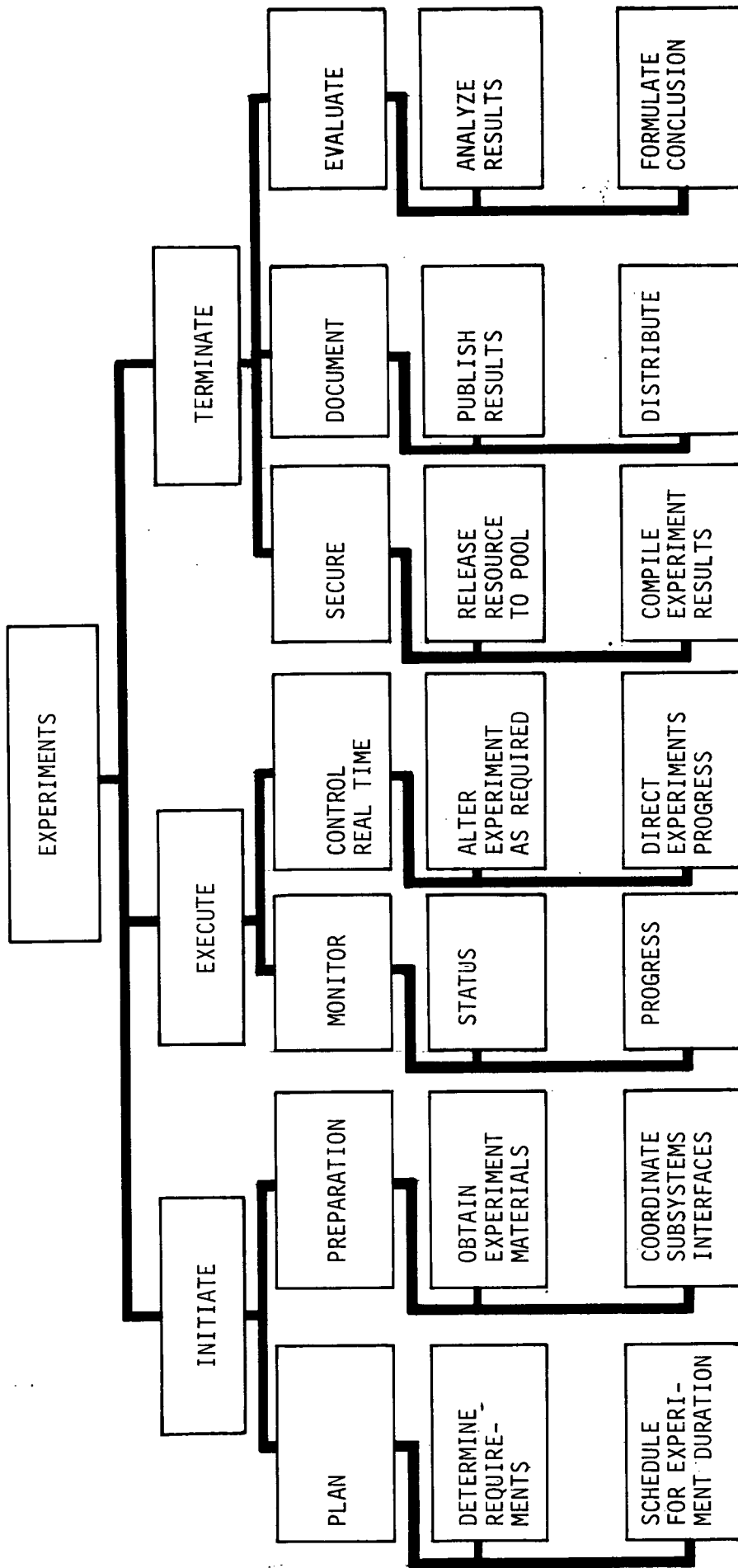


Figure A-6 EXPERIMENTS FUNCTION BREAKDOWN

experiments, this category of functions can be described and is applicable for all experiments. The level of crew involvement varies greatly between experiments, ranging from highly automated systems which require relatively little crew attention to hardware and experiments which would normally require nearly full time manning.

This category is divided into three subfunction groups. The first group is that of initialization. During the initialization phase, certain options are available to the experimenter or PI. These options make available the interconnection of program subroutine, allow for change in associated data, and the varying of limits for data gathering.

During execution time the experimenter may exercise the capability of checkpointing an experiment then pick it up later. An experiment may also be deferred or cancelled and deleted from the experiment schedule. On-line experiment control capability will allow the experimenter such control functions as data sampling rates and channel selection for analyzing experiment trends for the purpose of modification and scheduling of follow-on experiments.

The third group is concerned with experiment termination. The experimenter will be required to terminate and document his findings. The on-board computing system continually acquires and stores data from individual experiments which will be accessible for evaluation and documentation by the PI. Data conversion routines for converting to engineering tabulations will be available along with plots or graphs displaying the experiment results.

#### A.7 MANEUVER MANAGEMENT (Figure A-7)

The maneuver management category of functions was selected due to the number of other function categories which interface with vehicle maneuvers (example: flight control, guidance and navigation, etc.). This category is logically separated into three functions: (1) preparation, (2) execution, and (3) evaluation.

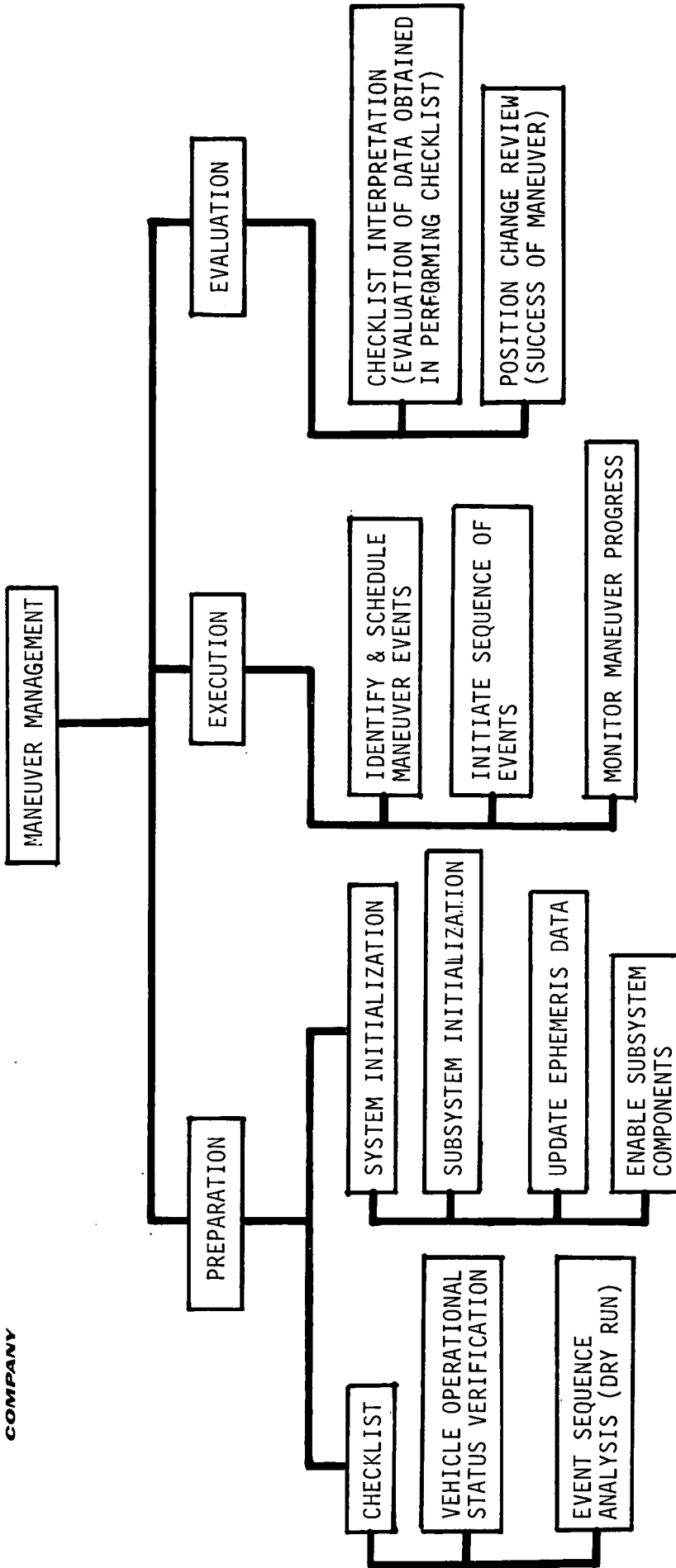


Figure A-7 MANEUVER MANAGEMENT FUNCTION BREAKDOWN

Preparation - In preparing for a vehicle maneuver, vehicle operational status is verified and a sequence of events established. The sequence in which the events must take place has to be confirmed. This usually requires a "dry-run." Prior to performing the actual maneuver subsystems must be initialized, G&N data must be updated and subsystem components enabled.

Execution - Execution will require that all events be scheduled, the event sequence initiated, and maneuver progress monitored.

Evaluation - An evaluation of each maneuver must be performed to:

- Determine checklist requirements
- Vehicle subsystem requirements
- Resource and expendable requirements

This data can be used in planning future similar maneuvers. The success of the maneuver must also be determined before a maneuver is completed.

#### A.8 OPERATIONAL STATUS (Figure A-8)

The operational status function category includes those functions required to maintain the crew and vehicle in operating condition. This includes preventive action as well as corrective action. This function category is subdivided into two functions, crew and vehicle.

Crew - Subs to this function are all functions required to sustain life on-board a manned space vehicle. Involved here are the environmental control and life support functions. Detail functions associated with environmental control are artificial atmosphere (i.e., air mixture, pressure, etc.), artificial gravity and temperature for both spacecraft and space suits. Detail life support functions are medical, mental and physical health, resource management (i.e., food, water, etc.), and waste management.

Vehicle - Subs to this function are on-board checkout and electrical functions. These subfunctions are self-explanatory, but the reason for making an electrical

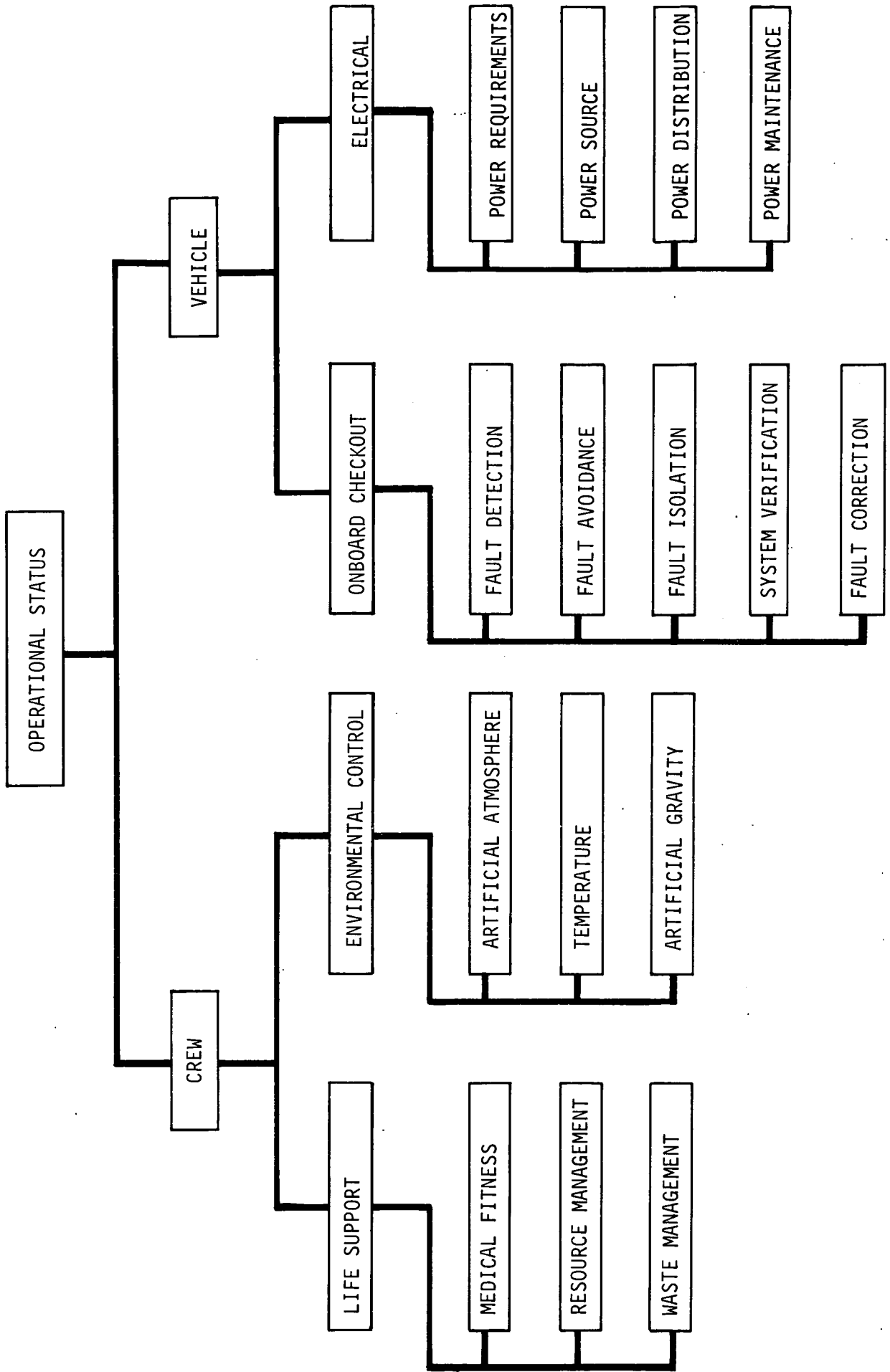


Figure A-8 OPERATIONAL STATUS FUNCTION BREAKDOWN



function may not be so obvious. The rationale behind this decision is based on the high degree of mechanization in future on-board checkout systems, and should electrical power go down or the total computer system fail, there would be no way to troubleshoot power failures. This separation is considered very important for future manned space flights.

#### A.9 MISSION INDEPENDENT CREW FUNCTIONS (Figure A-9)

The mission independent crew function category is a "catch-all" category for all non-critical crew functions (i.e., delay in performing will not have an adverse effect on the mission). The other characteristic of this category is that the requirement for the on-board computer in assisting crewmen in performing these functions is not obvious. Currently this category is subdivided into training and recreation functions.

Training - Performance of this function on-board space vehicles with long duration missions will require simulation techniques be utilized to maintain crew proficiency. Crew members will need methods for developing new skills for the purpose of backup. Depending on the method adopted is the degree of assistance required by the on-board computer. Beliefs are that with the large amount of on-board redundancy capability and current long life hardware, that special computer simulation programs will be required to keep on-board crewmen job proficient. To accomplish these on-board training requirements, self-instruction programs will be a requirement.

Recreation - Space crews must have recreational capabilities in the forms of entertainment, exercise, and relaxation. These functions are necessary to maintain morale and physical fitness.

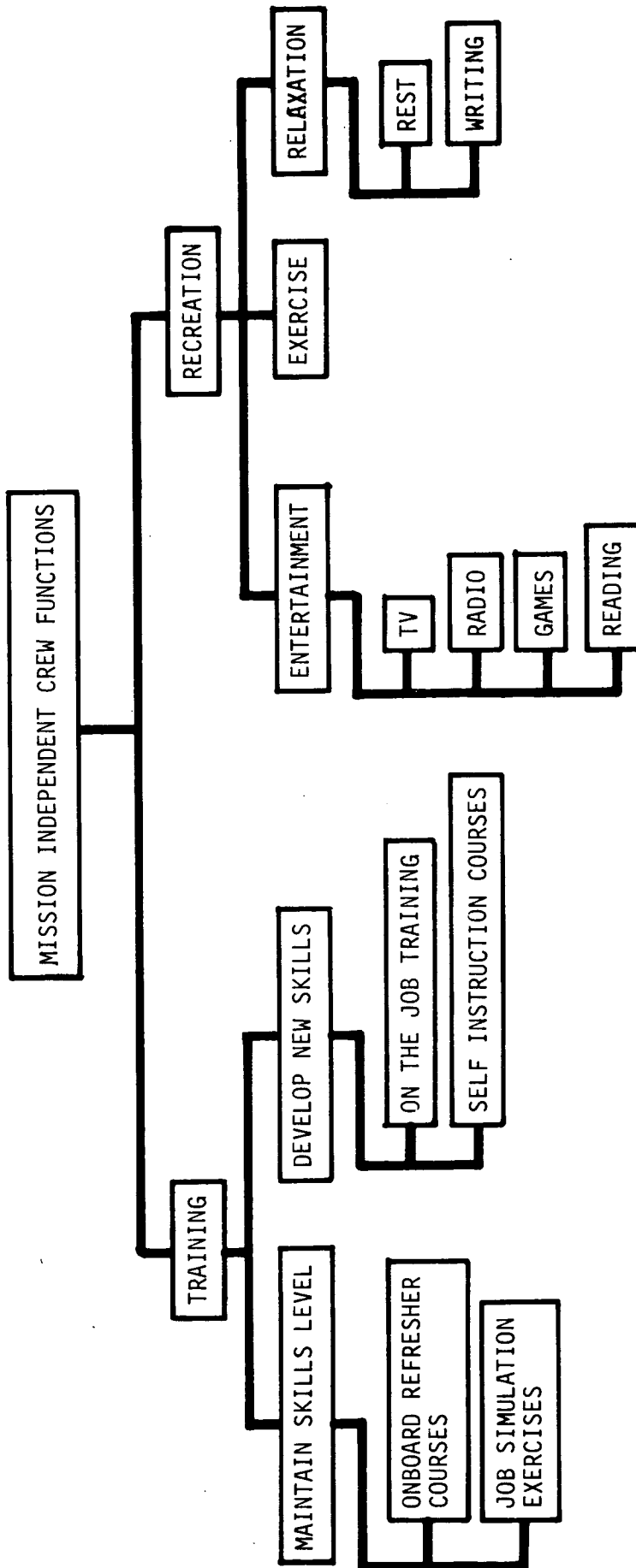


Figure A-9 MISSION INDEPENDENT CREW FUNCTION BREAKDOWN

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Appendix B

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Appendix B  
TYPICAL EXPERIMENT OPERATIONS\*

The Operating Procedure Flow Diagram (Figure B-1) depicts the operations performed during a normal experiment observation sequence. This flow is presented as a typical series of operations to illustrate the sequence of events in a prescheduled operations plan, and is not intended to reflect the many possible operations which might be performed at the discretion of the experimenter. The procedure is independent of any automation system that may be employed. However, it is assumed that for these operations the sequence begins with the astronomy module in position relative to the Space Station, and with all attitude control, power, and data handling systems active. Real-time control and monitoring is maintained on board the Space Station by the on-board experimenter, and overall experiment control is exercised from the earth by the principal investigator.

The following discussion provides details on each activity of the Operating Procedures Flow Diagram:

- Calibrate Telemetry: Astronomy module telemetry should be calibrated periodically during the operations. This is necessary to provide a high level of confidence in the resultant data and to provide calibration benchmarks for use in telemetry data reduction.
- Power-Up and Initialize Experiment: Power application to the experiment apparatus must be accomplished in a step-by-step fashion, verifying the proper completion of each step before the next is taken.
- Checkout Polarimeter: An active checkout of the polarimeter apparatus must be performed either as an integral part of the power-up sequence or after all power is applied. A function generator

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\*This Experiment and Solution Requirements were extracted from a report produced for NASA by System Development Corporation. The report title and number are "Analyses for the Requirements for Computer Control and Data Processing Experiment Subsystems--Experiment Control and Data Processing Requirements Specification Report" and TM-(L)-HU-033/000/00 respectively, dated 15 May 1970. Pages B-1 through B-4 are direct excerpts from the above report.

is used to check all experiment electronics except the proportional counters. A short scan of certain well known celestial X-ray sources will provide an adequate counter verification.

- Initialize Target Sequence: A list of targets and the order in which they are to be studied is prepared in advance of the experiment operation. In carrying out a normal observation sequence, the targets are scanned in the order indicated.
- Count Target Background: The X-ray background will affect the data study of a discrete X-ray source by adding to the total count. By noting the level of this background, compensation can be made in the data. Also, since the background count can provide valuable information about the level and wavelength of absorption by the interstellar media, it is an important clue to the density and composition of that media.
- Acquire Target: Target acquisition is accomplished automatically by the astronomy module pointing and control system on command from the Space Station. The Space Station observer accomplishes target verification by comparing aspect camera images with reference star fields.
- Select Polarimeter Rotation: The degree and rate of polarimeter rotation is specified by the principal investigator for each target. This information is stored along with other data in the target sequence list.
- Open Aperture Disc: Since the aperture disc partially occults X-ray emission, this operation assures that the disc is removed before observations of a target begin.
- Reset Scalers Registers and Data Buffers: Binary registers provide a running total of proportional counter outputs. This operation resets those registers in preparation for a new counting sequence.
- Begin Counting: This operation simultaneously opens the input gates to all of the binary registers to begin taking data.
- Scaler Overflow: Scaler overflow occurs when all bits in a binary register read "1" and another pulse is applied to the input.
- Count Above Acceptable Threshold: Very intense X-ray sources may tend to saturate the data handling capability of the experiment. This may be signified by a number of scaler overflows occurring in a specified period of time.
- Position Aperture Disc: This operation will result in a calculated reduction in counting rate.
- Read Pulsar Mode Data: The binary string which is the output of the pulsar mode counter is continuously scanned to reveal any source pulsations.

- Read Beam and Data Counts: Proportional counter outputs are sorted by pulse height analyzers into one of eight height levels and stored in appropriate binary buffers. These buffers are read to determine the number of counts and their approximate amplitude.
- Read All Scaler Data: High energy radiation such as gamma rays or heavy particle counts are signified by counts from the anti-coincidence circuitry or from the pulse shape discriminators. Binary scalers store these counts and are read to determine count rejects.
- Is Polarimeter in Last Position: The polarimeter table is rotated by applying pulses to a stepping motor. The number of steps and, hence, the degree of rotation is included in the target sequence list.
- Advance Polarimeter Position: This rotates the polarimeter table one step.
- Display and Store Target Data: Target data is automatically provided in preprocessed form to the Space Station observer and to ground personnel, and is stored for later analysis. "Raw" data is available upon request.
- Last Target: Operations are terminated when observations of the last target on the target list are complete.
- Power-Down: Power is automatically removed from the experiment apparatus in accordance with a pre-established procedure.
- Display Summary Data: Overall summary data will be provided in tabular and graphic form to supply "quick look" information on the results of the data sequence and to summarize the performance of on-board systems during the sequence.

A number of operations must be performed aboard the astronomy module which are of a routine nature. Periodic monitoring of secondary instrumentation such as voltage, temperature, pressure, etc., will be controlled by the experiment subsystem.

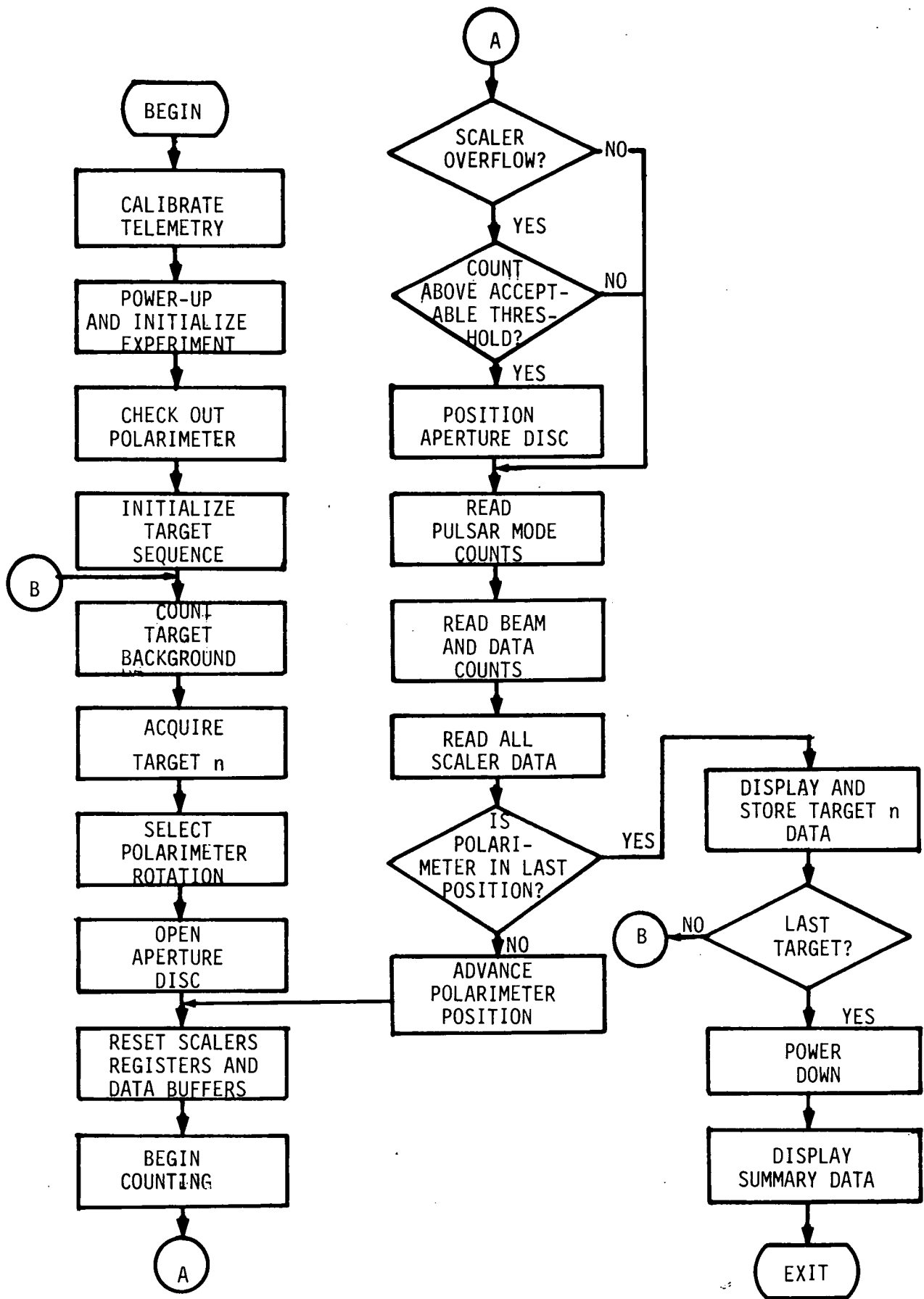
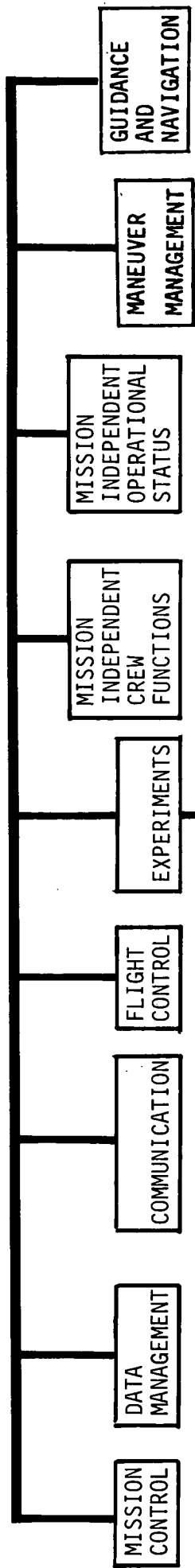
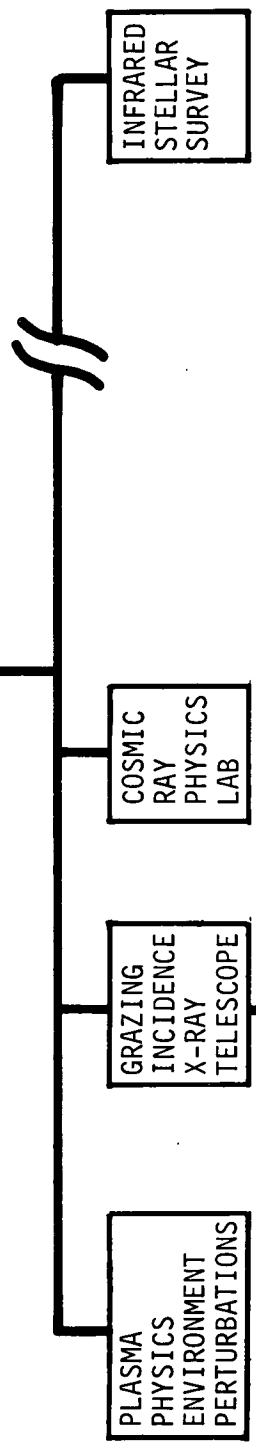


Figure B-1. OPERATING PROCEDURE FLOW DIAGRAM

FUNCTION CATEGORIES



26 FUNCTIONAL PROGRAM ELEMENTS



OPERATIONAL PHASES

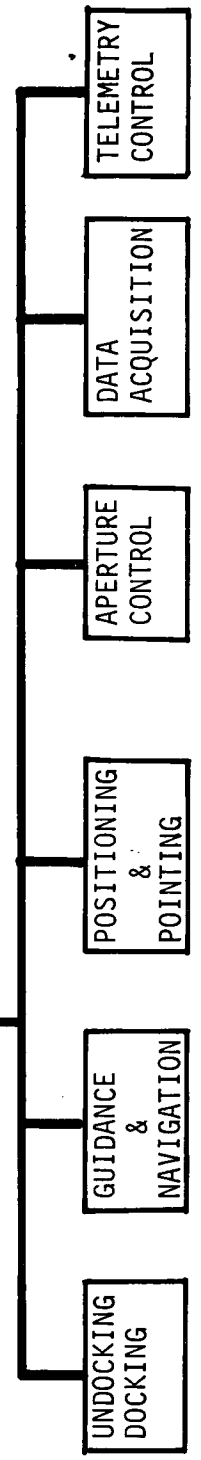
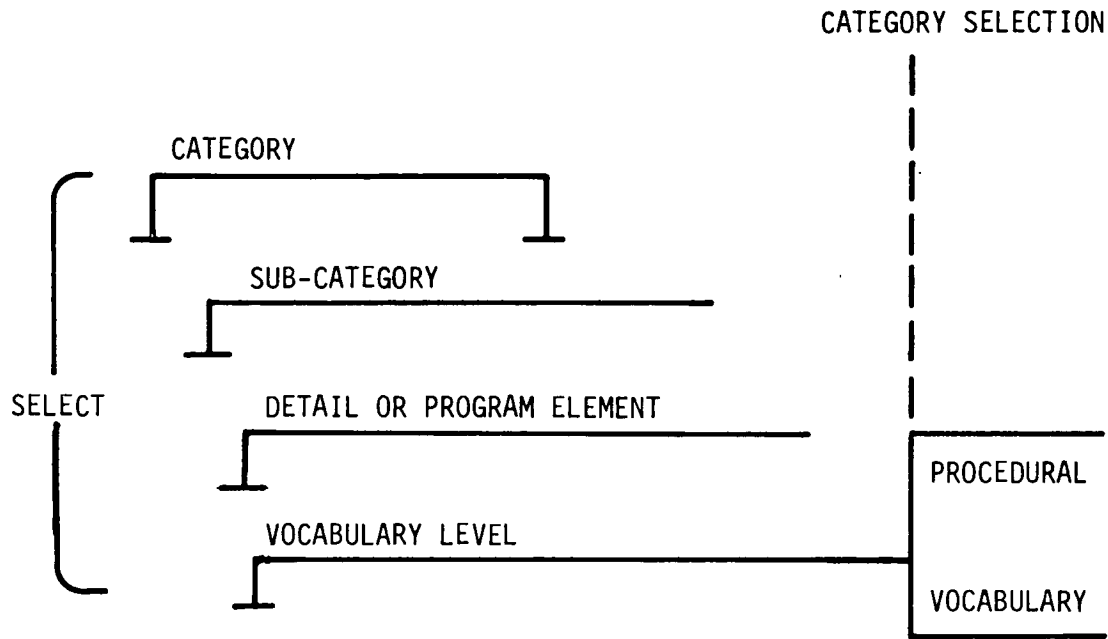


Figure B-2



# FUNCTION STRUCTURE BREAKDOWN



PROCEDURAL

VOCABULARY

## PROCEDURES (PROC) FUNCTIONS

EXAMPLE:

PROC = FPE = 5

● CALIBRATION

PROC = G/N, TRK-7, POS = STAR 4

● DISPLAY

● UNDOCKING/DOCKING

● POSITION

● G/N

● READ

● POSITIONING

● CHECK

● CONTROL

● SET/RESET

● DATA ACQUISITION

● EXECUTE

● TERMINATE

Figure B-3

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