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APOLLO IN-FLIGHT MAINTENANCE CONCEPT

Contract NAS9-150

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Exhibit I, Paragraph 3.5

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

FOREWORD

The In-Flight Maintenance (IFM) Concept was developed to convey the manner in which S&ID will support flight operations by providing in-flight maintenance. It constitutes the definition of IFM goals rather than the method by which these goals will be attained. It is directed toward the utilization of the efforts going into the overall IFM project development rather than the definition of these efforts.

The general concept of in-flight maintenance described in this report may be applied to the lunar excursion module (LEM); however, concurrent with the development of the LEM project, interface coordination must be continued with the associate contractor to insure the effectiveness of the overall spacecraft/IFM concept.

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INTRODUCTION

The inclusion of a three-man crew in the Apollo command module allows for the provisioning of a maintenance capability. The Apollo IFM will provide a maintenance capability with the realization that equipment reliability indicates minimum activity in this area. All aspects of maintenance and maintenance support are considered to assure that IFM goals will be met. These goals are defined as the development of a program that will most completely augment reliability, i.e., enhance the probability of mission success and crew safety. Studies which consider this augmented reliability versus the weight penalty imposed are being conducted continuously. Systems criticality is the primary factor in determining the extent of maintenance support to be provided for each system. An optimum reliability, through continuous assessment of maintainability, is mandatory for those systems deemed most critical, and may dictate the trade-off of maintenance support from those systems determined to be less critical.

This document outlines those maintenance activities that may be required during a typical Apollo spacecraft flight. It considers each mission phase as it affects maintenance and identifies the constraints imposed by the mission mode.

The maintenance support items required to accomplish the maintenance tasks effectively are listed.

A logic diagram and a written description of the information, and the decision and action requirements of the IFM program also are provided. This conceptual approach will be utilized by the spacecraft crew in accomplishing IFM.

The primary means of implementing the in-flight maintenance capability are use of the in-flight test system, provision of displays, spares, tools, technical data, training, and materials. This will support the crew member that is in the control position when he is making a maintenance-related decision or taking the corresponding required actions. The primary system (on-board) will furnish an independent detection and fault isolation capability to the spacecraft crew.

The ground operational support system (GOSS) will be considered as a back-up or auxiliary system. GOSS will have the capability of supporting the spacecraft crew in the determination of alternatives for a maintenance decision and resulting maintenance actions. It will also be capable of furnishing ground intelligence by making recommendations to the spacecraft-commander pertinent to the mission decision.

1.0 MISSION CONSIDERATIONS

1.1 INITIAL THRUST

The need to perform maintenance may arise at any point during the Apollo mission. However, the particular mission phase, because of work load, crew availability, or environmental conditions, may limit normal maintenance activities severely. A critical in-flight period on the Apollo equipment will be during the initial thrust. In this period of minimum maintenance activity by the crew, the spacecraft will be subjected to a high-g loading. During this phase, the crew safety system will be in control, and will become the determining factor in making and supporting the mission decision, i.e., primary, alternate, or abort.

1.2 EARTH ORBIT

During earth orbit and prior to the translunar injection phase, a relatively high crew task loading can be anticipated. Continuation of navigational sightings and other activities preparatory to the translunar injection can interfere with and/or postpone the performance of maintenance due to simultaneous tasks occurring in the same location within the command module.

1.3 TRANSLUNAR AND TRANSEARTH

The translunar and transearth coast periods provide the greatest opportunities for maintenance. Subsequent to the transposition of the lunar excursion module (LEM), and prior to lunar orbit injection, crew task loading will be relatively small. Crew task loading also will be small from the transearth injection until prior to earth reentry.

1.4 LUNAR ORBIT

The entire lunar orbit phase is considered to be a peak-load period. The division of the crew during lunar exploration imposes a very significant constraint upon maintenance. Any maintenance activity aboard the command module during this time must be of absolute necessity. Such maintenance activity may require the trade-off of other scheduled functions, such as those associated with guidance and control, and with communication. The time periods prior to LEM separation and after rendezvous will be fully occupied with various system checks, scientific observations, and scheduled tasks. The necessity for maintenance during these periods also may require a trade-off of other tasks.

1.5 EARTH REENTRY

The earth reentry phase, like the ascent phase, will be a period of relatively limited maintenance.

2.0 CONSTRAINTS

2.1 WEIGHT

Weight is the most significant constraint on the Apollo in-flight maintenance program. Weight has an indirect effect on IFM by imposing restrictions on equipment design. It has a direct effect on IFM by limiting the quantity of on-board spares and other maintenance facilities.

2.2 MISSION PHASE

During thrust periods, crew members will be restrained to their couches. This will limit maintenance to those functions that can be accomplished by the manual use of switches consistent with existing g-forces.

During the period of lunar orbit and exploration, maintenance capability will be restricted by crew nonavailability.

2.3 CREW CONSTRAINTS

Crew constraints generally can be divided into several categories: those imposed by the adverse environment; those imposed by the hardware design, crew equipment and accessories; and those imposed by psychophysiological load capabilities.

2.4 EQUIPMENT ACCESSIBILITY

Physical placement of equipment within the command and service module also will limit, and sometimes may preclude, maintenance on some equipment. Prime consideration shall be given to the priority placement of critical equipment to ensure that an optimum maintenance capability is provided.

3.0 MISSION EVENTS LOGIC

3.1 MISSION EVENTS LOGIC EXPLANATION

Mission events logic is provided to indicate the relationship of maintenance to mission tasks. Figure 3-1 is a diagram of mission events logic. An explanation of the logic portrayed by the diagram is presented in subsequent sub-paragraphs. The numbers below the events on the diagram correspond with the paragraph numbers.

3.1.1 Spacecraft Status - Mission Events

It can be discerned from the mission events logic that the crew is continuously monitoring displays. It is apparent that as long as all indications remain normal the mission decision would be to continue the existent mission. Following the mission decision are three alternative actions, each supported by the information required to fulfill the requirements of the selected action. The remainder of the diagram represents the information decision action aspects of the performance of mission tasks.

3.1.2 Indications Normal (Decision)

As a function of the continuous monitoring spacecraft status, the crew is constantly making the Indications Normal decision. This concept is directed at the activity arising from an Indications Normal No decision.

3.1.3 Criticality Criteria (Information)

Criticality becomes a highly complex outgrowth of mission phase, equipment utilization, and alternate modes of operation available. This criteria must support two decisions by the crew; first, the degree of criticality at the time of failure and, second, the effect of the failure on the mission decision even though repair is accomplished.

3.1.4 Critical (Decision)

A Critical No decision has a dual meaning; first, the failed function is not critical now, nor will it be for the remainder of the mission and, second, the failed function is not critical now, allowing the maintenance task to be deferred for a time. A Critical Yes decision indicates that immediate action must be taken to eliminate the danger to the crew or to minimize mission degradation resulting from the failed function.

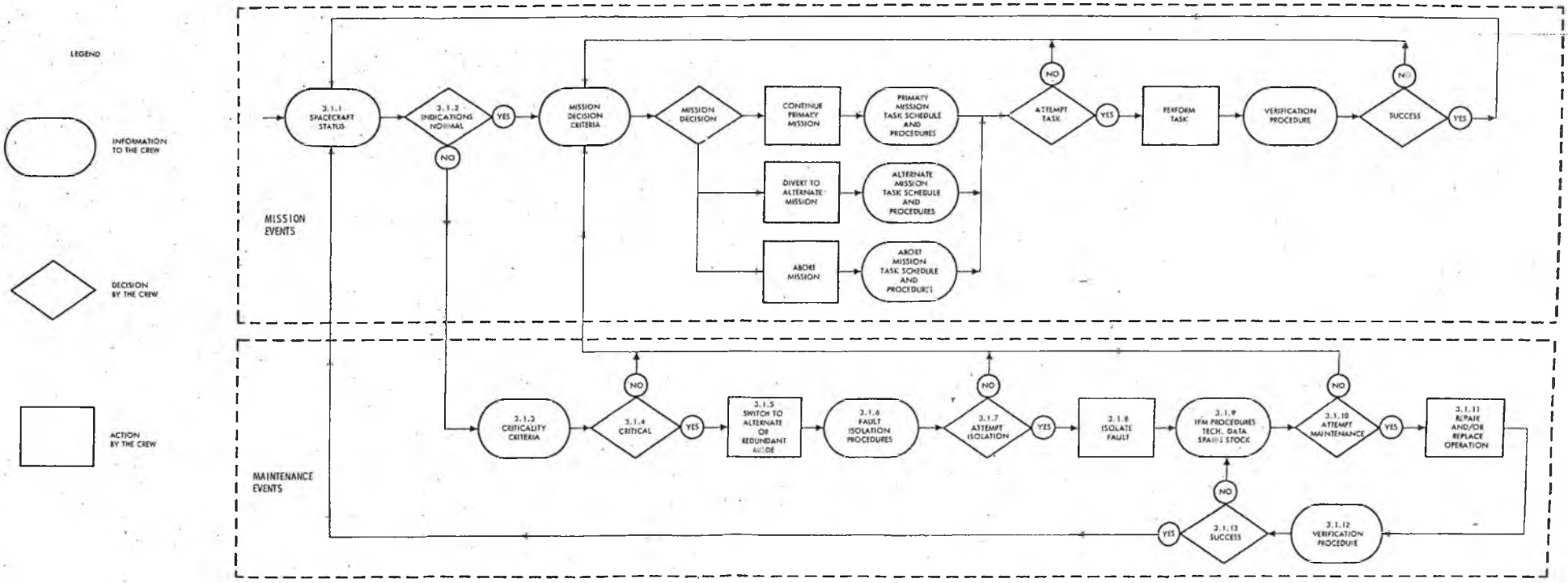

Figure 3-1. Mission Events Logic

3.1.5 Switch to Alternate or Redundant Mode (Action)

The availability of alternate or redundant modes provides for the first maintenance action. In some cases these modes will support an emergency function. In other cases it may provide support for a less critical function as an indirect result of that support provided for critical functions.

3.1.6 Fault Isolation Procedures (Information)

Isolation procedures will be provided in support of every maintenance action available to the crew.

3.1.7 Attempt Isolation (Decision)

A No decision to attempt isolation may result from the Critical decision (Paragraph 3.1.4) that the type of failure would disallow continuation of the primary mission. It also may be caused by a failed function that has no maintenance support. A Yes decision would allow the crew to proceed with the isolation.

3.1.8 Isolate Fault (Action)

Utilizing the in-flight test sytem (IFTS) micro-monitor and the isolation procedures, the crew will isolate the fault to the failed item.

3.1.9 IFM Procedures, Technical Data, Spares Stock (Information)

After the failure has been isolated, pertinent procedures, technical data, and spares stock must be reviewed to assure support of the remove/replace task.

3.1.10 Attempt Maintenance (Decision)

An Attempt Maintenance No decision would indicate that no maintenance exists for this failure or that the maintenance support has been expended. A Yes decision would indicate that a maintenance capability exists.

3.1.11 Repair and/or Replace (Action)

Generally repair will be limited to adjustments servicing and/or calibrations and will have procedural coverage. Utilizing the procedures provided, the repair and/or remove and replace task will be accomplished.

3.1.12 Verification Procedures (Information)

After repair has been accomplished, the system must be verified to assure that the systems function has been restored.

3.1.13 Success (Decision)

A Success No decision would indicate that the maintenance was not successful. In this case the flight crew will consider making another attempt to repair the failed item. A Yes decision indicates that the system function has been restored. This completes the maintenance task. However, even though maintenance has been successful, the crew must evaluate the new conditions caused by expending a portion of the maintenance support, with regard to the mission decision.

4.0 QUALITATIVE MAINTENANCE INFORMATION

4.1 MAINTENANCE DECISION

Specific information is required to support in-flight maintenance. This information must be comprehensive enough to support the flight crew when they are making maintenance related decisions or performing maintenance actions. Figure 4-1 illustrates some of the requirements for information to support these decisions. From this information the crew can select the appropriate action. Following are some of the actions that may be selected individually or in combined form.

Tolerate condition
Switch to a redundancy
Switch to an alternate mode
Replace
Repair
No maintenance possible

After the maintenance decision has been made and appropriate action has been taken, the effect of the maintenance event must be evaluated. The flight crew will make the mission decision predicated on the effect of the maintenance event on crew safety and mission success. Following are three conditions that illustrate the impact of the maintenance event. The mission decision is made by indicating yes or no to each condition in sequence.

Crew safety or probability of success have not been degraded beyond continuation of primary mission.
New conditions will allow an alternate mission.
Abort is required.

The method of displaying this information to the crew will be detailed in the In-Flight Maintenance Plan. One manner of presenting a large part of the decision-making criteria is a maintenance-oriented time line. The presentation of the planned mission reflecting total crew activity, equipment utilization, mission events, mission decision points, will point out the allowable maintenance periods and the possible trade-offs.

Another decision element will be the task times associated with a specific maintenance contingency. The mission time available versus the actual task time required may have a large effect on the maintenance or mission decision.

INFORMATION REQUIRED FOR MAINTENANCE DECISION AND ACTION	YES	NO	TIME
The function is critical, or time is critical			X
The condition can be tolerated			X
There is an alternate mode or redundancy			X
The mission time	X	X	
Time remaining until the function becomes critical	X	X	
Time remaining to next decision point	X	X	
There is a maintenance capability			X
There are fault isolation procedures			X
There are replace or repair procedures			X
Maintenance task times under existing conditions (shirt sleeve, vented suit, or pressurized suit)	X	X	
There is a trade-off required			X
A trade-off is possible			X
Maintenance was successful			X

Figure 4-1. In-Flight Maintenance Information Requirements

4.2 MAINTENANCE ACTION

Figures 4-2 and 4-3 demonstrate the support of the maintenance programmed for a specific mission. These figures, though they are still in the formative state, will reflect the analysis effort and the coordination of information for each maintenance action available to the crew. They will furnish criteria and information required for in-flight maintenance procedures and flight crew training. These figures are proposed for inclusion in the IFM Plan, however a separate negotiation will be required as the effort is considered to be beyond the scope of the present contract.

Each component of spacecraft systems having an in-flight maintenance action possible in the form of a spare, redundancy, or repair (adjustments, servicing, or calibrations) will be analyzed to determine the type of failure, system protection provided, failure indications, isolation elements, accessibility, and effect on system functions. In-Flight Maintenance Analysis, Figure 4-2, and Isolation and Task Times Analysis, Figure 4-3, will be used to provide a tabulation of all maintenance planned for each mission. Figure 4-2 analyzes each item having a planned maintenance action. Figure 4-3 groups these items by common malfunction indications and keys the failures to first-level isolation and related task times. Additional methods for anlysis will be developed with regard to alternate modes of operation. These will be included in subsequent revisions of this document and detailed in the IFM Plan.

4.2.1 In-Flight Maintenance Analysis

An explanation of the information to be entered in each column of the In-Flight Maintenance Analysis form follows. Where information indicated by column heading is not applicable to an individual item, the word "none" will be entered.

Column 1 - List each unit for which an in-flight maintenance capability exists in the form of a spare, redundancy, or repair.

Column 2 - List the type of possible failures, such as out of tolerance, shorted, etc., opposite the individual unit.

Column 3 - List the system protection, circuit breaker, relief valve, sensor switch, etc., provided for the unit after it malfunctions.

Column 4 - List the caution and warning signals that are associated with the item malfunction.

Column 5 - List the control and display indications that are associated with the item malfunction.

Column 6 - List the IFTS/micro-monitor indication (lights) associated with the unit malfunction, down to the first level of isolation.

Column 7 - List the stimuli requirements associated with the isolation of the malfunction of this unit.

Column 8 - List and identify the system test points associated with isolating a unit malfunction.

Column 9 - List the system test point voltage required to isolate the unit malfunction.

Column 10 - Provide information primarily oriented to units having a repair capability. Also provide information for removal and replacement of units. Accessibility will be qualified as:

a. Readily Accessible - Those units available directly for repair or removal and replacement without displacement or removal of other units.

b. Secondarily Accessible - Those units which are accessible for maintenance only after other units have been displaced or removed.

c. Inaccessible - The location of the malfunctioned item precludes maintenance.

Column 11 - List the spacecraft function that may not be performed because of the malfunction and the effect that the malfunction will have on other systems.

4.2.2 Isolation Analysis and Task Times

Isolation Analysis and Task Times, Figure 4-3, will be prepared utilizing the data from the In-Flight Maintenance Analysis. This form consolidates and groups the units having an in-flight maintenance planned capability in accordance with their common IFTS and/or micro-monitor malfunction indication. The information provided by this form will support the development of in-flight maintenance procedures. An explanation of the information to be entered in each column of the form follows. Where information indicated by column heading is not applicable, the word "none" will be entered.

Provided Maintenance Items Spared Redundant Adjustable	Type of Failure	System Protection	Failure Indications			Isolation Elements			Accessibility	Lost Function and Effect on Other Systems	Remarks
			Caution and Warning	Controls and Displays	IFTS/Micro-Monitor	Stimuli Requirements	System Test Points	System Test Point Voltage			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)

Figure 4-2. In-Flight Maintenance Analysis

IFTS/Micro Monitor Indication	Stimuli Requirements	Possible Failed Units	System Protection	System T/P Connector and Pins	System Test Point Voltage	Effect on System or Systems	Isolation Task Times			Remove, Replace, Adjust Task			Verification Task Times			Total Related Task Times		
							S/S	V/S	P/S	S/S	V/S	P/S	S/S	V/S	P/S	S/S	V/S	P/S
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)			(9)			(10)			(11)		

Figure 4-3. Isolation and Task Times Analysis

Column 1 - List the IFTS and/or micro-monitor indications (lights) associated with the planned in-flight maintenance.

Column 2 - List the stimuli requirements associated with the individual indication (light).

Column 3 - Group and list all possible failed units associated with an individual indication (light) opposite the indication in Column 1.

Column 4 - Enter the system protection, i.e., circuit breakers, relief valves, etc., required to prevent system damage in event of failure of a unit opposite the individual unit listed in Column 3.

Column 5 - Identify and list system test points, connectors and pins associated with fault isolation relative to an individual IFTS and/or micro-monitor indicator (light) opposite the indication listed in Column 1.

Column 6 - List the system test point voltage and tolerances opposite the respective test points in Column 5.

Column 7 - List the information relative to the effect on system or systems as the result of a unit failure opposite the possible individual failed unit in Column 3.

Column 8 - Enter information concerning the gross isolation task time under shirt sleeve, vented suit, pressure suit conditions related to an individual IFTS and/or micro-monitor indication.

Column 9 - Enter information concerning the remove and replace and/or repair task times for an individual unit under shirt sleeve, vented suit, pressure suit conditions.

Column 10 - Enter information concerning the task times for verification after maintenance under shirt sleeve, vented suit, or pressure suit conditions.

Column 11 - Enter information that will reflect the "worst case" task times for isolation, remove, replace, repair, and verification under shirt sleeve, vented suit, or pressure suit condition associated with the individual indication (light) on the IFTS/micro-monitor. "Worst case" constitutes cases whereby failure cannot be defined to one unit and all possible units must be changed to correct the condition.

5.0 MAINTENANCE PLANNING

5.1 REQUIREMENTS

In-flight maintenance planning encompasses all considerations having an influence on the successful accomplishment of the basic maintenance objective. This objective is the maintenance of equipment in an operable condition which will ensure mission success. Major considerations of maintenance planning are causative factors, categories of maintenance, and maintenance tasks.

5.1.1 Causative Factors

The three major factors that initiate maintenance requirements are known degradation of equipment due to time and/or usage, malfunction or failure, and accidental damage of equipment. Known degradation of equipment will be provided for on a scheduled, preplanned basis. The remaining factors will be provided for in the form of a maintenance capability based on probability and criticality. Section 6.0, Maintenance Support is concerned with this capability. The probability of accidental damage to equipment can only be related to the precise design tolerances of the equipment and the physical location of the equipment within the spacecraft.

5.1.2 Maintenance Categories

Maintenance is categorized as scheduled maintenance (preventive) and unscheduled maintenance (corrective). Scheduled maintenance is that maintenance which is planned on the basis of known degradation of equipment due to time interval or usage. Unscheduled maintenance is that maintenance required as a result of malfunction or failure of equipment.

5.1.3 Maintenance Tasks

Scheduled maintenance tasks comprise such actions as inspection, servicing, adjustment, calibration, and confidence testing. In the performance of anyone of these tasks, discrepancies or deficiencies may be revealed that will result in unscheduled maintenance. Unscheduled maintenance tasks encompass such actions as malfunction detection, fault isolation, and repair. Before any maintenance event is concluded, inspection and/or verification will be performed to ensure that equipment is both operational, and safe for continued operation.

It can be generally stated that the majority of corrective maintenance will be directed at the electronics systems. In most cases this maintenance will be limited to the isolation of malfunctions and the replacement of replaceable units. The limitation of maintenance to replaceable units does not preclude the possibility of crew discretion-type fixes where damage or malfunction causes are readily discernible. The repair function also will include the adjustment, servicing, and calibration required to return the system to normal operation.

The on-board capability to perform malfunction detection, isolation, and system verification consists of the trained flight crew, caution and warning system, controls and displays, the IFTS, the micro-monitor system, and availability of pertinent technical data. The continuous monitoring of systems by the flight crew will provide information relative to the in-limit/out-of-limit condition of gross systems within the spacecraft. The IFTS provides the means wherby the flight crew can isolate a malfunction down to an individual unit or combination of units within a system. Also, it will provide the capability to evaluate systems degradation. In this manner, a determination may be made that the system will still function within mission objective requirements although a malfunction is indicated. Detailed procedures for isolation of malfunctions within the spacecraft systems will be available to the flight crew during a mission. Procedures for verification of systems after corrective maintenance has been performed also will be available to the flight crew.

An augmentation of the on-board malfunction detection, isolation, and verification capability will be provided by GOSS. By use of telemetry, GOSS will monitor various points within the spacecraft systems. This will not only provide additional detection capability, but will provide the capability of sensing an impending malfunction. This additional capability is inherent by reason of the continuous monitoring of system signals and the sensing of a degradation of a signal before it has exceeded its allowable parameter. Through GOSS, by use of available communication links, scientific and engineering analyses and information can be transmitted to the flight crew relative to maintenance problems arising in the spacecraft.

Fault detection and isolation utilizing the on-board capbility and GOSS have been discussed. However, situations may arise for which no detection capability is provided. Such conditions may be detected by the crew through sensory means. These conditions can be transmitted through GOSS to ground operations for analyses. In turn, ground analyses and recommendations will be transmitted to the spacecraft crew for appropriate action.

The maintenance procedures in the manual for ground crew operations will duplicate the IFM procedures but will be more detailed to include information to support the advisory or confirming comment between the GOSS networks and the Apollo flight crew relative to maintenance problems. GOSS, with the aid of this manual, will be capable of supporting the spacecraft crew in making maintenance decisions and taking maintenance actions.

The primary maintenance functions, scheduled and unscheduled maintenance, will be organized so that all maintenance procedures are subject to time-line operational events and system criticality. Information will be readily available.

6.0 MAINTENANCE SUPPORT

6.1 SPARES

Spares will be predicated on systems criticality, probability of failure, and weight and volumetric restraints in the command module and will only be provided for those systems that are accessible and maintainable.

6.2 TOOLS

The selection of the in-flight maintenance tools will be based upon their capability to accomplish the required task effectively. The possibility of providing a dual purpose capability and minimizing redundancy also influences the selection of this equipment. Other tool and equipment considerations are:

1. Minimum weight
2. Compatibility with space suit
3. Operability in a weightless environment to 1-g environment
4. Operability in a low-pressure ambient environment
5. Operability in an extreme temperature environment
6. Accommodation for carrying a crewman in-flight maintenance belt assembly
7. Ready accessibility
8. Efficient psychomotor utilization
9. Operability in a 100 percent oxygen environment

6.3 TECHNICAL DATA

Technical data in support of the maintenance functions will be provided in a comprehensive and compact form. It will be aligned to the in-flight test system and will be relevant to the on-board maintenance capability.

6.4 EQUIPMENT

The equipment to support maintenance consists of the in-flight test system, the micro-monitor system (primary) and GOSS (auxiliary). A general description of the functions of these systems is found in Paragraph 5.1.3.

6.5 MATERIEL

The materiel required to support maintenance will be identified after equipment replacement, repair, and test requirements have been defined clearly.

6.6 TRAINING

The flight crew will be trained in the recognition of system degradation, detection and diagnosis of systems malfunctions, and the determination of corrective action. Such training will begin as part of the system management training for the guidance and navigation, communications and data, stabilization and control, and environmental control systems, and will continue in an integrated systems trainer. Practice will be given on this trainer in systems checkout and in system analysis for spacecraft malfunctions. Main panel controls and indicators, the in-flight test system, and simulated systems information from the integrated mission control center (IMCC) and ground operational support system (GOSS) will be used.

Training will be given concerning any removal and replacement of components or the obtaining of access for repair. Practice by the flight crew in analyzing contingency situations and in determining action to be taken will be included in exercises for the Apollo part task trainer (APTT) and the Apollo mission simulator (AMS). To develop flight-crew flight-controller coordination in these in-flight maintenance procedures and decisions, combined exercises will be programmed with the operational support personnel (IMCC/GOSS).

6.7 PROCEDURES

The procedures will be prepared as an aid to trained personnel. The crew procedures will be limited by obvious weight and space availability. Thus, only actual maintenance procedures will be displayed, i.e., confidence test, fault isolation, remove, replace, and repair (adjust, service, or calibrate), and verify. A more complete IFM procedures manual will be prepared for ground crew operations.

CONCLUSION

This document establishes the requirements for an effective in-flight maintenance program. It defines the maintenance functions and support categories insofar as the state of equipment design will allow.

The maintenance function, irrespective of where it is accomplished, is, by necessity, the same. The basic difference is in the constraints and environmental conditions under which the maintenance is performed.

The in-flight maintenance program will be predicated on an ability to minimize the effects of constraints and environmental conditions, and on the logical design of equipment maintainability within these conditions. Also, it will depend on an ability to predict analytically the probability of failure and the provisioning of redundancies, spares, and material in support of the required maintenance actions.

The end product will be the sum of the knowledge and efforts of all the sciences in the provisioning of a complete and workable in-flight maintenance program.

GLOSSARY OF TERMS

This glossary defines terms that relate to the Apollo Program in general. It is specifically applicable to the Apollo Maintenance Concept SID 62-702, the Apollo Maintenance Plan SID 62-702-2, the Apollo In-Flight Maintenance Concept SID 63-328, and will be applicable to all subsequently produced maintenance planning documentation.

ACCEPTANCE	The act of an authorized representative, by which the customer approves specific services rendered, or acknowledges that certain specified articles are in conformity with the requirements of the contract.
ACCESSIBILITY	The relative ease with which a component or an assembly can be approached to be repaired, replaced, or serviced.
ACCESSORY	A mechanism or device employed to facilitate or increase the effective use of some other mechanism or piece of equipment.
ADJUSTMENT	A means by which parts, as of a machine or device, are adjusted to one another to attain an operating standard peculiar to the unit.
AIRFRAME	Assembled structural and aerodynamic components of a spacecraft or launch vehicle.
ARTICLE	A unit of hardware, or any portion of the hardware, required by the contract.
ASSEMBLY	Refer to Addendum.
ATTACHMENT	A supplementary device fastened to or mounted on a machine, apparatus, or other end item, so as to vary or extend its basic function.

BENCH MAINTENANCE EQUIPMENT (BME)	Equipment required to support component and subsystem testing. It is designed to provide the capability of isolating and defining malfunctions.
BOILERPLATE	A simulated module for predevelopmental and developmental tests leading to the design of the spacecraft module.
BULK ITEMS	Certain raw materials and semi-fabricated items used in the manufacturing of an article, e.g., bolts, nuts, washers, hoses, clips, lubricants, fasteners, clamps. These materials and items include standard, commercial, and military hardware, and the design manufacturer's standard parts falling within the same category.
CALIBRATE	A method of comparing an instrument, device, or dial with a standard to determine its accuracy, capacity or graduations, or devising a scale.
CALIBRATION TESTS	Tests conducted to determine the input-to-output characteristics of a measuring device, component, or assembly; these tests are also conducted to verify that the characteristics are within specified tolerances.
CHECKOUT	A sequence of operational and calibrational tests needed to determine the condition and status of a required operational function.
COMBINED SYSTEMS	The physical and functional combination of systems and structures yielding one vehicle, e.g., command module or service module.
COMMAND MODULE	The personnel and control vehicle in Apollo, containing command and communication facilities and crew provisions.

COMMON AND STANDARD ITEMS	Certain items of common and standard use, commercially available to industry, that adequately satisfy the requirements of the end article.
COMMON HARDWARE	Certain items having multiple applications, e.g., nuts, bolts, screws, washers, pins, keys, grommets, rivets, etc.
COMMON TOOLS	Tools in general use that are applicable to a variety of materiel, e.g., screwdrivers, hammers, drill presses, etc.
COMPONENT	Refer to Addendum.
CONFIGURATION	The physical nature of an item; the physical arrangement of components which comprise a spacecraft and its dimensions.
CONSUMABLE MATERIAL	A type of item that is expended through use.
CONTRACT SCHEDULE	The prime contract executed by the Government and the prime contractor which, in addition to the terms and conditions thereof, includes by reference or otherwise, specifications, drawings, exhibits, and other data necessary to its proper discharge.
CONTRACTOR	The individual(s) or concern(s) who enters into a prime contract with the Government, e.g., North American Aviation, Inc.
CONTRACTOR FURNISHED EQUIPMENT (CFE)	An item of equipment provided by the contractor under the terms of a contract.
CONTROLLED ENVIRONMENT	An environment in which factors such as humidity, pressure, and temperature are under control.

CONTROLLED PARTS	Parts, assemblies, or components which require lot or serial number identification.
CORRECTIVE MAINTENANCE	Maintenance performed on a non-scheduled basis to restore equipment to a serviceable condition.
CRITICAL MATCHING ASSEMBLIES	Assemblies that are specifically matched to a particular spacecraft, GSE end item, trainer, or simulator.
CRITICAL MATCHING PARTS	Parts that are specifically identified for use on a particular spacecraft, GSE end item, trainer, or simulator.
CRITICAL MATCHING SPACECRAFT SUPPORT HARDWARE	Assemblies that require specific fit to the individual vehicle.
CUSTOMER	The National Aeronautics and Space Administration (NASA).
CUSTOMER WORK ORDER (CWO)	An S&ID form which authorizes the performance of certain work such as the overhaul, repair, or modification of equipment. The CWO is used to identify and control items during the overhaul, repair, or modification cycle.
DELIVERABLE EQUIPMENT	All manufactured hardware that is complete to the degree required, and ready for delivery to any scheduled destination.
DIAGNOSIS	The process of identifying a malfunction to the level of component, assembly, or part at which the maintenance action will be taken.
DIRECT SUPPORT MATERIEL	Property which may be incorporated into or attached to an end item, or which may be consumed or expended in the performance of a contract. It includes raw and processed material,

	parts, assemblies, components, and small tools and supplies which may be consumed in normal use in the performance of a contract.
DISPLAY	Oscilloscopes, counters, dials, printers, lights, indicators, scales, etc., used to provide visual intelligence.
END ITEM	A space system or any of its principal systems or subsystem elements, e.g., launch vehicle, spacecraft, ground support system, propulsion engine, or guidance system; also, articles which will be delivered directly to a Government installation or provided as GFP to a contractor.
ENVIRONMENT	The aggregate of the conditions and forces that influence or affect an article and its performance throughout its service life.
EXPENDABLES	A category of materials that are not accountable upon issue.
FAILURE	An occurrence, produced by sudden or gradual deterioration, which causes equipment performance to deviate from specified limits.
FAILURE RATE	The average number of failures occurring per unit of time in a specified piece of equipment.
FAULT ISOLATION	The process of determining the cause of failure within a given system.
GOVERNMENT FURNISHED AERONAUTICAL EQUIPMENT (GFAE)	All types of aeronautical equipment that is supplied by the Government to the prime contractor or subcontractor for incorporation into the end item.
GOVERNMENT FURNISHED EQUIPMENT (GFE)	Equipment furnished to the contractor by the Government.

GOVERNMENT FURNISHED PROPERTY (GFP)	All property in the possession of, or acquired directly by the Government, and subsequently delivered or otherwise made available to the contractor.
GROUND SUPPORT EQUIPMENT (GSE)	All non-flight implements or devices required to inspect, test, adjust, calibrate, appraise, gage, measure, repair, overhaul, assemble, disassemble, transport, safeguard, record, store, actuate, or otherwise perform a function in support of the spacecraft and boilerplate during (1) tests at factory subsequent to manufacturing completion, (2) prelaunch, launch, and postlaunch operations at test sites, and (3) major development tests such as house spacecraft tests, propulsion tests, and environmental tests. This includes equipment required to support ground support equipment as defined herein.
HANDBOOKS	In a general sense, any small book containing specialized information or instructions.
IDENTIFICATION	A term referring to a controlled serial or lot number which relates the part, assembly, model, etc., to a particular lot of raw material, manufacturing process, manufacturer, manufacturing date, cure date, receiving date, purchased lot, historical record, test data, calibration data, assembly process, matched equipment, expiration date.
INDIRECT SUPPORT MATERIEL	Equipment, machinery, structures, and consumable materiel, used on a recurring basis, for outfitting, maintaining, or operating purposes; and maintenance stock, tool crib supplies, stationery, office supplies, non-productive hardware, fuel, bottled water, dry ice, etc.

IN-FLIGHT MAINTENANCE	The use of available maintenance accessories and technical information, in accordance with procedures established in the In-Flight Maintenance Plan to augment the probability of mission success and maximize crew safety.
INSPECTION	The examination, including testing, of contract work, articles, and services to determine conformance to contract requirements.
INSPECTION AGENCY	A Government agency, or an agency acting on behalf of the Government, which determines that contracted work, articles, and services conform to technical requirements.
INSPECTION, FINAL	An inspection which may occur either at the contractor's plant or at any other designated location and whose purpose is to verify compliance with applicable drawings, and/or specifications, and to insure conformance with requirements of the contract.
INSPECTION, PRELIMINARY	An inspection which is performed at the contractor's plant or plants and whose purpose is to establish that the articles inspected are in conformity with requirements of the contract prior to shipment to the place of final inspection and acceptance.
INSPECTION, RECORD	Final inspection and acceptance which are acknowledged in a binding manner by an authorized representative of the customer.
INTEGRATED SYSTEM	The physical and functional combination of two or more vehicles to form a spacecraft or launch vehicle, e.g., Apollo spacecraft.

INTEGRATED SYSTEMS TEST	A test of a vehicle or stage with two or more systems involved.
INTERCHANGEABLE UNITS	Assemblies, subassemblies, and replaceable parts that can be substituted for one another without physical or electrical modification.
INTERCHANGEABILITY	A property given a part so that it may be used in more than one application.
INTERFACE	In a rocket vehicle or other system, a common boundary between one component and another; the junction points or the points within or between systems or subsystems where matching or accommodation must be properly achieved in order to make their operation compatible with the successful operation of all other functional entities in the space vehicle and its ground support.
INTERIM RELEASE/ EMERGENCY RELEASE	An authorization to proceed with fabrication or procurement of long lead time items prior to the normal approval cycle.
LAUNCH COMMIT	That point in time when the vehicle is actually released.
LAUNCH ESCAPE SUBSYSTEM (LES)	A subsystem providing for command module recovery in case of mission abort after launch and prior to orbit, and consisting of the launch escape motor, launch escape tower, and tower jettison motor.
LOGISTICS SUPPORT	The support given by an organization to an activity by means of which are furnished all, or any part of, its supplies, equipment maintenance, transportation, storage, or any other like service, so as to enable the activity to carry out its intended operation more expeditiously.

LOT SCHEDULE	A schedule directing that an item be inspected, crated, and readied for shipment prior to the lot number date, and shipped in the time period assigned.
LONG LEAD TIME ITEMS	Items that cannot be delivered within a short time span because of their complexity of design, complicated manufacturing processes, or limited production or procurement cycles.
LUNAR EXCURSION MODULE (LEM)	The two-man vehicle which will land on the moon after the Apollo spacecraft enters lunar orbit.
MAINTAINABILITY	A quality of the combined features of materiel design and installation that permits or enhances the accomplishment of maintenance by personnel of average skill. Materiel design parameters include such items as the operational and environmental conditions under which the maintenance functions will be performed. Also included are repairability and serviceability, which are functions of the ease with which maintenance activities may be performed to avert or correct malfunctions.
MAINTENANCE	All actions required to retain materiel in, or restore it to, a serviceable condition. Its phases include servicing, repair, modification, overhaul, test, inspection, and condition determination.
MALFUNCTION	A general term used to denote the inability of a product to give satisfactory performance. It need not constitute a failure if readjustment of operator controls can restore an acceptable operating condition.
MATERIAL	The substance or goods out of which an item is, or can be, made.

MATERIEL	Items of all kinds required for the equipment, maintenance, operation, and support of activities.
MEAN REPAIR TIME (MRT)	The expected mean-value of the active, repair/work time required to restore a system, equipment, or component to a condition of satisfactory operation.
MODIFICATION	A change in the design of an item, effected in order to correct a design deficiency, to facilitate production, or to improve operational effectiveness.
MODULE	A combination of components contained in one package, or so arranged that together they are common to one mounting, which provides a complete function or functions to a system and/or subsystem in which it operates. (See command module, service module, lunar excursion module, etc.)
NASA'S DELEGATED REPRESENTATIVE	A representative of NASA stationed at a supplier's plant, or a representative of the inspection agency to whom quality assurance functions have been delegated.
NON-REPARABLE	An item designed and procured with the intention of disposing of it at failure rather than attempting repair.
OVERHAUL	The rebuilding or extensive repairing and reconditioning of an item of equipment which has deteriorated through testing or extensive use.
PACKAGING	The cleaning, preservation, and packing in unit quantities; interior cushioning and bracing; design and utilization of interior and exterior containers; identification of contents of inner and outer containers; and loading.
PART	Refer to Addendum.

PECULIAR AND NONSTANDARD ITEMS	Items peculiar to the equipment design of the contractor, subcontractor, or supplier for which no known common or standard item can be substituted, and for which design approval may not have been received.
PREVENTIVE MAINTENANCE	The inspection, care, and servicing required to maintain equipment and facilities in a serviceable condition.
PRIME CONTRACTOR	North American Aviation, Inc., Space and Information Systems Division.
PROCEDURES	The step-by-step manner in which any given task is performed.
PROTOTYPE MODEL	A model suitable for complete evaluation of electrical and mechanical form, design, and performance. In its final form it employs approved parts and is completely representative of final equipment.
PURCHASED PARTS	Articles manufactured by outside sources in conformance to S&ID drawings and identified by S&ID part numbers.
RACE SYSTEM	"Rapid Action Coordinated Effort"; the emergency requisition system of the prime contractor, used to expedite materiel support requirements.
RECLAMATION	The process of recovering required, serviceable, and economically reparable components and materials.
REFURBISH	Restoration of an item to its original configuration. This may include modification as required.
RELEASE	An approval to fabricate or procure items of materiel support.

RELIABILITY	The probability that a system, subsystem, component, or part will perform its required functions under defined conditions at a designated time and for a specified operating period.
REPAIR	The restoration of a system or equipment to a satisfactory operating condition after malfunction, damage, or deterioration.
REPAIRABILITY	The probability that when maintenance action required by equipment malfunction is taken, (1) the system will be restored to a satisfactory operating condition in a given period of time with a given manpower expenditure; and (2) the equipment will remain in satisfactory operating condition over a specified period of time.
REPLACEABLE SERIALIZED UNIT	The smallest serialized unit that can be replaced without soldering.
REPLACEMENT	The substitution of one unit for another functionally identical unit.
REPLACEABLE PACKAGE OR MODULE	Refer to Addendum.
SERVICEABILITY	A function of equipment design, configuration, installation, and operation that indicates the degree to which maintenance requirements are minimized and simplified.
SERVICEABLE CONDITION	That condition in which the article is considered suitable for carrying out the purpose for which it was designed or authorized.
SERVICE LIFE	The period of time or number of functional performances during which an item, installed in an operational system, will be expected to remain in a serviceable condition.

SERVICE MODULE	The Apollo module containing propulsion equipment fuel, reaction control systems, and communications power. Used for thrust after booster separation, mid-course correction, lunar orbit, lunar orbit ejection, and earth return midcourse correction, it is jettisoned prior to re-entry.
SERVICING	The work performed at regular intervals, or under a recognized system, to keep equipment operable. It includes cleaning, inspecting, lubricating, adjusting, charging, and changing of filters, desiccators, etc.
SHELF LIFE	That period of time during which an item can remain in storage without having its operability affected.
SITE SUPPORT LIST	A list of materiel items essential to the support of a scheduled program at a field site.
SPACECRAFT	In the Apollo program, any component or combination of components of the flight vehicle not part of the launch vehicle, e.g., launch escape subsystem, command module, service module, or adapter.
SPARE PART	Any part, subassembly, or component kept in reserve for the maintenance and repair of major items of equipment.
SPECIAL TOOLS	Specially designed tools required to perform a special function of maintenance, assembly, disassembly, etc.
SUBASSEMBLY	Refer to Addendum.
SUBCONTRACTOR	An organization, company, or manufacturer that is under contract to a prime contractor, and has been delegated the responsibility for design, manufacture, and support of a system.

SUBSYSTEM	Refer to Addendum.
SUPPLIER	A contractor or subcontractor actually performing the services or producing the contract articles.
SUPPORT MANUAL	A publication containing detailed information on technical procedures, including instructions on handling, inspection, storage, operation, maintenance, checkout, repair, modification, and overhaul of given equipment.
SYSTEM	Refer to Addendum.
TEST ARTICLE	An item that appears on a contractor, subcontractor, or vendor drawing and will be utilized as a subject of a test.
TEST SITE	A facility established at a selected geographic location for conducting a specific operation or test.
TEST SUPPORT PART	A part that is required for a unique application to accomplish a test function, and will not appear on a contractor, subcontractor, or supplier drawing as a functional part of that drawing.
TRACEABILITY	A term that refers to the ability to trace the history, application, use and location of an item.
TRADE-OFF	The procedure of trading a degree of one attribute to gain a degree of another attribute, e.g., sacrificing a degree of performance to obtain a greater degree of reliability under certain conditions, or vice versa.
UNIT	Refer to Addendum.

GLOSSARY ADDENDUM

Note: The following definitions are presented in sequential order to provide an understanding of system relationships from the highest to the lowest level of elements.

SYSTEM	Any combination of complete operating equipment, comprised of a grouping or interconnection of subsystems or other functional entities, capable of performing a specific operational function or functions. Included are aerospace systems, support systems, command and control systems, and all associated materiel. A system may also be a procedural entity which accomplishes a specific task, e.g., a quality system.
SUBSYSTEM	A major element in a system, comprised of a single module or combination of modules plus independent components that contribute to modular functions, all interconnected and interrelated within a system and performing a specific system function.
REPLACEABLE PACKAGE OR MODULE	An item of equipment that may be mounted in or removed from a spacecraft, checkout console, or the like, as a single package. A replaceable package or module is a combination of components contained in one package, or so arranged that together they are common to one mounting, which provides a complete function or functions for a system and/or subsystem in which it operates.

COMPONENT	A functional part of a system, subsystem, replaceable package or module, that is essential to an item's operational completeness. A component is a combination of units or parts that together may be functionally independent of, or an independent entity within, a complete operating module or subsystem, but which provide a self-contained function necessary for proper module, subsystem, and/ or system operation.
UNIT	An assembly, or any combination of parts, subassemblies, and assemblies mounted together, normally capable of independent operation in a variety of situations.
ASSEMBLY	A combination of parts or subassemblies that may be taken apart without destruction, which has no application or use of its own, but is essential for the completeness of a more complex item with which it is combined. An assembly is an element of a component and performs functions necessary to the operation of the component as a whole.
SUBASSEMBLY	A combination of parts comprising a definable entity of an assembly, a unit, or a component, which performs a function essential to the proper operation of the assembly, unit, or component.
PART	The smallest subdivision of a system; an individual piece having an inherent functional capability, but unable to function without the interaction of other parts or forces, and ordinarily not subject to disassembly without destruction.

A-LEVEL MAINTENANCE	All the activity necessary to service, adjust, and evaluate the readiness of a system, and which can be performed with minimum delay. It includes maintenance which is within the limits of equipment configuration and within the verification capability of GSE common to systems and integrated systems checkout.
B-LEVEL MAINTENANCE	Replaceable package maintenance accomplished by use of replaceable units and which is within the verification capability of GSE common to replaceable package checkout.
C-LEVEL MAINTENANCE	All the maintenance activity associated with the Apollo program which is beyond the A and B levels including total repair, modification and overhaul capability.

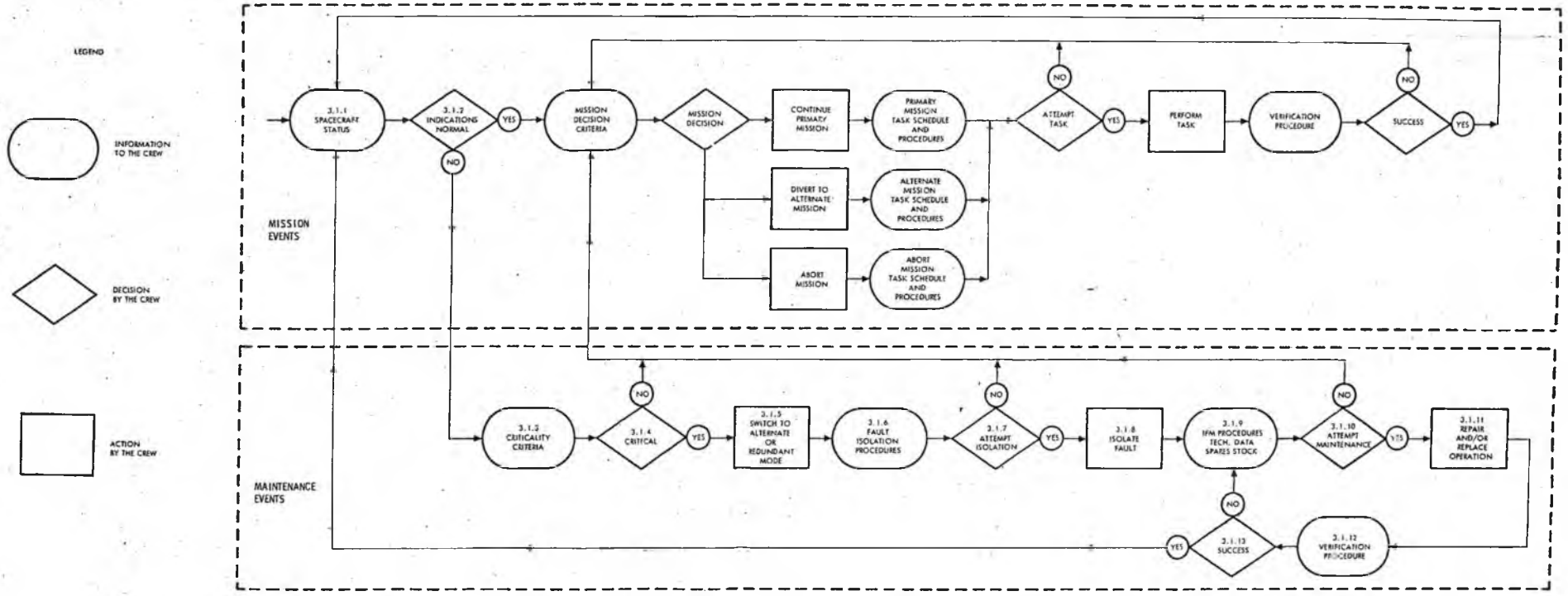

Figure 3-1. Mission Events Logic

Provided Maintenance Items Spared Redundant Adjustable	Type of Failure	System Protection	Failure Indications			Isolation Elements			Accessibility	Lost Function and Effect on Other Systems	Remarks
			Caution and Warning	Controls and Displays	IFTS/Micro-Monitor	Stimuli Requirements	System Test Points	System Test Point Voltage			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)

Figure 4-2. In-Flight Maintenance Analysis

IFTS/Micro Monitor Indication	Stimuli Requirements	Possible Failed Units	System Protection	System T/P Connector and Pins	System Test Point Voltage	Effect on System or Systems	Isolation Task Times			Remove, Replace, Adjust Task			Verification Task Times			Total Related Task Times		
							S/S	V/S	P/S	S/S	V/S	P/S	S/S	V/S	P/S	S/S	V/S	P/S
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)			(9)			(10)			(11)		

Figure 4-3. Isolation and Task Times Analysis