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APOLLO EXPERIENCE REPORT - TEST AND CHECKOUT

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16. Abstract

The problem areas encountered during the development of the acceptance testing and preflight checkout requirements and procedures for Apollo spacecraft are discussed. Recommendations are given for cases in which methods used in the Apollo Program are considered to apply to future space flight programs.

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SUMMARY

Acceptance testing of Apollo spacecraft was conducted during manufacturing and assembly to determine conformity to design or specifications as a basis for acceptance. Testing at the launch site was conducted primarily to reverify performance of individual launch vehicle stages and modules as received from the factory. Experience gained in dealing with many of the problems encountered during the Apollo Program in these areas of activity can be applied to future space flight programs. The following representative problem areas are discussed: checkout documentation, change implementation, test configuration control, retest philosophy, destacking considerations, desirability of preinstallation acceptance tests, factory or field testing, use of nonflight equipment during checkout, desirability of propulsion system firing tests, vacuum testing considerations, crew equipment stowage tests, checkout of redundant functions, integrated subsystem checkout, and checkout tolerances.

INTRODUCTION

The original Apollo philosophy was to provide flight-ready vehicles to the launch site. The reasons for establishing this objective were twofold: first, the early detection of any hardware defects would result in an earlier resolution of any problem and, second, the factory would be better equipped to replace hardware. This philosophy was not completely realized because parts were not available and because subsequent identification of requirements for some testing facilities required the installation of the parts at locations other than the factories for reasons of safety and economy.

Acceptance testing of an Apollo spacecraft was conducted in conjunction with the manufacturing and assembly process. Testing was conducted at the launch site primarily to ensure that the performance of each subsystem had not degraded after factory checkout and to verify that the spacecraft/launch vehicle interface, launch team, and launch support equipment were ready.

Problem areas encountered during the Apollo Program are discussed in this report. In general, the areas discussed are within the scope of the spacecraft testing activities; however, several examples pertain to launch vehicle testing. Two approaches are taken in the discussion of the test and checkout activities. One approach is to state conditions or procedures that led to difficulties, then describe how the situation was rectified and recommend approaches for future programs. In other cases, recommendations are given for dealing with general problem areas without reference to specific problems. A glossary of special terms is given in appendix A.

CHECKOUT DOCUMENTATION

The preparation and control of test and checkout plans and the procedures for preparation and launch of Apollo spacecraft were specified in Apollo Program Directive No. 26-B. This directive (reproduced in appendix B) required that the NASA Lyndon B. Johnson Space Center (JSC) (formerly the Manned Spacecraft Center (MSC)) prepare and approve a Test and Checkout Requirements Document and a Test and Checkout Specifications Document for submittal to the John F. Kennedy Space Center (KSC) 4 months before delivery of a flight vehicle. These documents, in turn, provided the basis for the development of the test and checkout plans by KSC.

Developing two separate documents for each vehicle resulted in the documents being organized such that cross-referencing was inconvenient. This led to misunderstandings between the design engineers and the test engineers concerning the compatibility of specifications and requirements. The problem was subsequently rectified by combining the documents into one so that a specification with an appropriate tolerance is given for each requirement (fig. 1). Future programs should follow the same approach for specifying test and checkout requirements and tolerances. Other documentation schemes that have worked well and should be applied to future programs are as follows.

1. The launch-site and factory test plans followed the internal indexing or numbering system of the Test and Checkout Requirements Document. This consistency in numbering provided a convenient method of tracking requirements through all test documentation.

2. One document was used as a basis for all vehicles. Then, at each revision, the requirements peculiar to vehicles that had been launched were deleted, and new requirements were incorporated. This technique not only reduced the paper volume but also kept the document current and minimized the amount of outdated material. An additional advantage was that continuity was maintained from vehicle to vehicle.

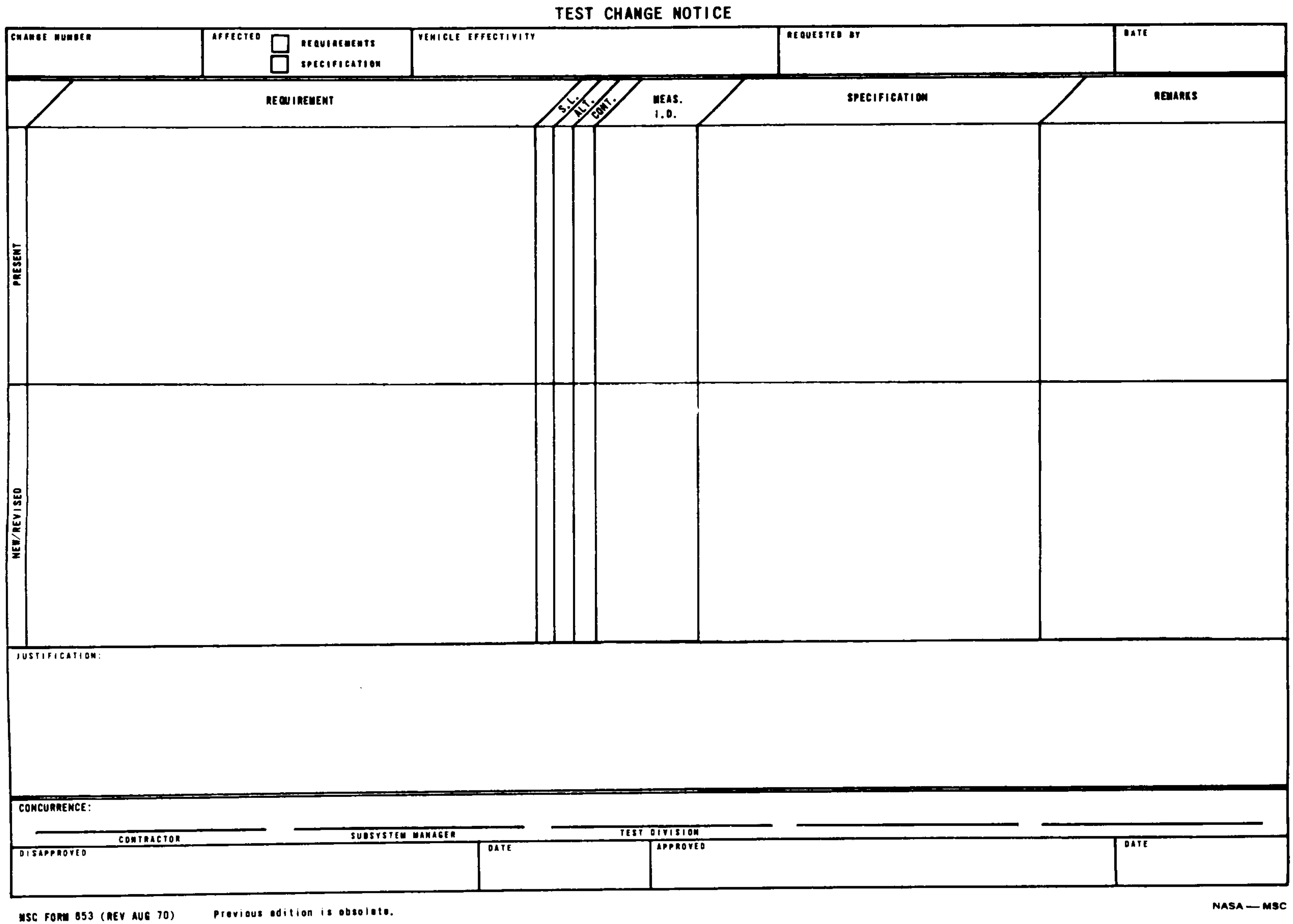
3. Changes to the test documentation at KSC were made by test change notices (MSC Form 653, fig. 2), which described the present and proposed requirements and the justification for the change. All test change notices were approved by the Program Manager except in cases in which a delay in approval could have resulted in problems in meeting scheduled milestones or in cases where the change had been previously approved through Configuration Control Panel/Configuration Control Board action. In these instances, the signature authority was delegated to the resident manager of the Apollo Spacecraft Program Office at KSC. The most significant aspect of the change system was the minimal amount of paperwork required to make a change. Any organization could generate the change and submit it for approval immediately, if required.

TEST REQUIREMENTS AND SPECIFICATIONS

Paragraph	Requirement	Sea level	Altitude	Contingency	Meas. ident.	Specification	Constraints and Remarks
3.6.1.E.2	2 SPS gimbal responses to individual pitch and yaw attitude GYRO (AG) errors						All response polarities same as inputs except yaw nozzle movement is opposite
	AG error inputs ±P and ±Y					12.0°	
	Pitch GPI					2 ±0.6°	
	Yaw GPI					2 ±0.6°	
	Pitch gimbal position				CH3517	2 ±0.6°	
	Yaw gimbal position				CH3518	2 ±0.6°	
	SPS engine nozzle movement, pitch					Z direction	
	SPS engine nozzle movement, yaw					Y direction	
3.6.1.E.2	3 SPS gimbal responses to individual pitch and yaw rate GYRO (RG) errors						TVC servo power 2 on other position
	RG error inputs -P and -Y					-2.0°/sec	
	Pitch GPI					-2.0 ±0.6°	
	Yaw GPI					-2.0 ±0.6°	
	Pitch gimbal position				CH3517	-2.0 ±0.6°	
	Yaw gimbal position				CH3518	-2.0 ±0.6°	
3.6.1.E.2	4 TVC static null stability						10 sec min duration
	Gimbal trim commands, P & Y					0.0°	
	Pitch GPI					0 ±0.6°	
	Yaw GPI					0 ±0.6°	
3.6.1.E.2	5 SPS gimbal responses to individual pitch and yaw gimbal trim commands						Polarity of response same as command
	Gimbal trim commands, ±P and ±Y					3.5°	
	Pitch GPI					3.5 - 1.4° + 1.0°	
	Yaw GPI					3.5 - 1.4° + 1.0°	
3.6.1.E.3	TVC Integrators						
3.6.1.E.3	1 Gimbal position/trim						A. Gimbal motors off B. P & Y integrators enabled
	GPI, pitch and yaw					3.0 ±1.0°	Primary and secondary TVC
	TVC total error, pitch null				CH3523	0 ±0.2 VDC for 10 sec	P TW adjustment
	TVC total error, yaw null				CH3524	0 ±0.2 VDC for 10 sec	Y TW adjustment
	Gimbal trim TW, pitch and yaw					GPI value ±1.4°	
3.6.1.E.3	2 TVC integrator responses to ± pitch AG errors, LM off (CSM 112-114) or hi gain (CSM 116-119)						A. SPS gimbal motors off B. 3.6.1.E.3.1 gimbal position trim, primary or secondary only, required

MSC FORM 1099 (Rev Mar 70) NASA — MSC

Figure 1.- Example of documentation of test requirements and specifications.


TEST CHANGE NOTICE

CHANGE NUMBER	AFFECTED ☐ REQUIREMENTS ☐ SPECIFICATION	VEHICLE EFFECTIVITY	REQUESTED BY	DATE

	REQUIREMENT	S.L.	ALT.	CONT.	MEAS. I.D.	SPECIFICATION	REMARKS
PRESENT							
NEW/REVISED							

JUSTIFICATION:

CONCURRENCE:

CONTRACTOR

SUBSYSTEM MANAGER

TEST DIVISION

DISAPPROVED	DATE	APPROVED	DATE

MSC FORM 853 (REV AUG 70) Previous edition is obsolete.

NASA — MSC

Figure 2.- Example of form used for test change notices.

CHANGE IMPLEMENTATION

Hardware, software, and procedural changes requiring implementation during testing and checkout led to difficulties that could have been prevented if inadequacies had been recognized earlier. Examples of difficulties that were experienced are cited in the following paragraphs, and procedures to minimize delays and prevent accidents are recommended.

Tests were disrupted when connectors were disconnected or ground support equipment (GSE) was shut off to permit a change. A technique was developed to alleviate problems of this nature by including periods in the test flow to incorporate blocks of changes. Use of this technique allowed uninterrupted testing and optimized work accomplishment during modification periods.

In some cases, malfunctions resulted when seemingly straightforward activities that should have been conducted in series were performed in parallel. During a modification period, all activities should be controlled in a manner similar to that exercised during the test activity. This provides proper integration of all activities and ensures that systems safety is not compromised.

Another difficulty occurred when all aspects of a major change were not incorporated at one time, even though modification periods were in effect. The compatibility of a total change was normally proofed in an integrated systems ground test article, but a partial change was generally not tested in that program. Partial changes resulted in many aborted acceptance tests. A procedure should be implemented to flag partial change incorporation. A special assessment must be made to determine the effectiveness of tests that are conducted before completion of the total change.

Another area of concern was the cancellation of a major change after it had been partially incorporated. In some cases, partially incorporated changes resulted in unnecessary equipment and circuits that could have caused flight failures. For example, electrical wiring installed as part of a major change and left installed after the major change was canceled resulted in an electrical shorting condition in the command module during one unmanned Apollo flight. An administrative procedure is required to prevent this type of occurrence.

The converse of the preceding example also applies. Changes incorporated to deactivate equipment already installed require positive assurance that all interfaces have been deactivated. For electromechanical equipment, deactivating only the mechanical functions could produce an electrical hazard or result in a flight failure. In the command module, a waste management system blower was deactivated by disconnecting and plugging the hardlines; however, electrical control of the blower was not changed or deactivated. The inadvertent activation of a switch caused the blower to operate against a deadheaded system, resulting in burning out the blower motor. The failure modes and effects analysis should be updated for each contemplated change to prevent situations such as this from occurring.

TEST CONFIGURATION CONTROL

The vehicle configuration must be verified before any test is started. This verification includes determining that the latest modifications have been incorporated; assuring that all required components have been installed, required electrical connectors mated, and fluid lines connected; and assuring that cabin valves, circuit breakers, and switches are in proper positions. With respect to the GSE, the setup must be verified, the required fluid samples taken, and the switch/valve configuration verified.

Once the test is started, rigid control must be exercised to maintain test discipline. This is accomplished by having approved procedures for test and by requiring documentation of discrepancies. (Documentation of checkout test anomalies proved to be very difficult to control during the Apollo Program.) Usually, discrepant conditions should be analyzed before a test is continued, but this is not always possible. Discrepancies should be thoroughly documented as to how the vehicle/GSE is configured and how the problem manifests itself. The troubleshooting philosophy should be approved, and each step must be documented before its accomplishment.

For example, during the prelaunch checkout of the Apollo 16 spacecraft, a situation occurred as a result of improper test configuration evaluation. During the troubleshooting of a leaking quick-disconnect fitting, the pressure was vented from the GSE manifold to facilitate the valve changeout. However, the GSE/spacecraft configuration was such that venting of the manifold placed a negative pressure on the spacecraft burst disks. This negative pressure caused the burst disks to rupture and the spacecraft propellant tank bladders to collapse. As a result, the spacecraft had to be destacked so that the propellant tanks and integral bladders could be replaced.

RETEST PHILOSOPHY

There are many instances during the lifetime of a vehicle when connectors are disconnected, lines broken, components replaced, and similar actions taken. Occurrences such as these cause loss of confidence in previously established test integrity; therefore, a retest philosophy and plan are required. System-level and vehicle-level acceptance tests are continually proofing the integrity of the entire system and/or vehicle. A plan that will set forth the philosophy and basic requirements for the reestablishment of proof of integrity is required in the early stages of checkout. The detailed retest plan will be a major undertaking in any future program. Such a plan was developed for the Apollo Program. This plan contained a matrix of all spacecraft connectors and showed where the integrity of each connector was verified during the checkout process. Many connectors were verified more than once, and this plan reflected each verification. Because of this matrix, rapid determinations of retest requirements were easily made. In addition, when verification of connectors could be delayed until a later test date, valuable test time was saved because special retests were not required. The retest philosophy used in the Apollo Program is presented in the following subsections. This philosophy is recommended as a baseline for retest requirements.

General Retest Ground Rules

Reverification may require additional testing or may utilize downstream testing, but the reverification should be accomplished before beginning the Flight Readiness Test. However, if troubleshooting or a replacement is required during the Flight Readiness Test, the reverification must be accomplished before completing the Flight Readiness Test by rerunning the appropriate test procedures sequences. The documentation that identifies and authorizes the operation resulting in invalidation of previous testing must include the specific retest requirements for reverification and the vehicle or test constraints.

Retest procedures for each connector, control panel, and spacecraft component should be prepared before test as an adjunct to the standard operational test procedures. Retesting combinations of panels, components, and connectors will often result in some items being checked two or more times. The number of combinations involved is enormous. Constraints, switch matrices, and GSE usage, for example, have to be evaluated. Because of these factors, retest procedures cannot always be preplanned unless it is decided to repeat all basic operational checkout procedures, which would necessitate excessive retest time. It was often necessary in the Apollo Program to create retest procedures in real time by combining parts of existing procedures and creating new ones as the case demanded.

Retest Ground Rules for Electrical Assemblies

Before a replacement assembly is installed, it must be preinstallation tested in accordance with existing specifications and time limitations to verify that the assembly, by itself, meets the required performance criteria. Any suspect or failed assembly removed from the spacecraft must be recycled through a preinstallation test and any additional bench-level test required to isolate malfunctions. Units that exhibit intermittent failures should not be reinstalled in the spacecraft until the cause of the failure is found and corrected.

When an electronic assembly is replaced in the spacecraft by a different unit, all functional modes and all functional paths to and through the replacement assembly should be reverified and, in some instances, an end-to-end recalibration conducted. Nonsuspect assemblies removed from the spacecraft to allow access to other equipment do not require bench-level testing before reinstallation. In this instance, an interface integrity test should be performed. All connectors that are demated must have continuity reverified after remating. After replacement or repair, continuity and electrical isolation should be reverified.

Retest Ground Rules for Fluid and Mechanical Systems

The replacement of components or the breaking of any fluid system requires, at a minimum, leak tests of the remated connections and cleanliness reverification of the reworked area. Functional verification in the spacecraft is required on replaced components.

Mechanical assemblies that have been functionally tested in the spacecraft and subsequently invalidated because of removal or replacement (or both) of a component should be reverified for fit and function.

DESTACKING CONSIDERATIONS

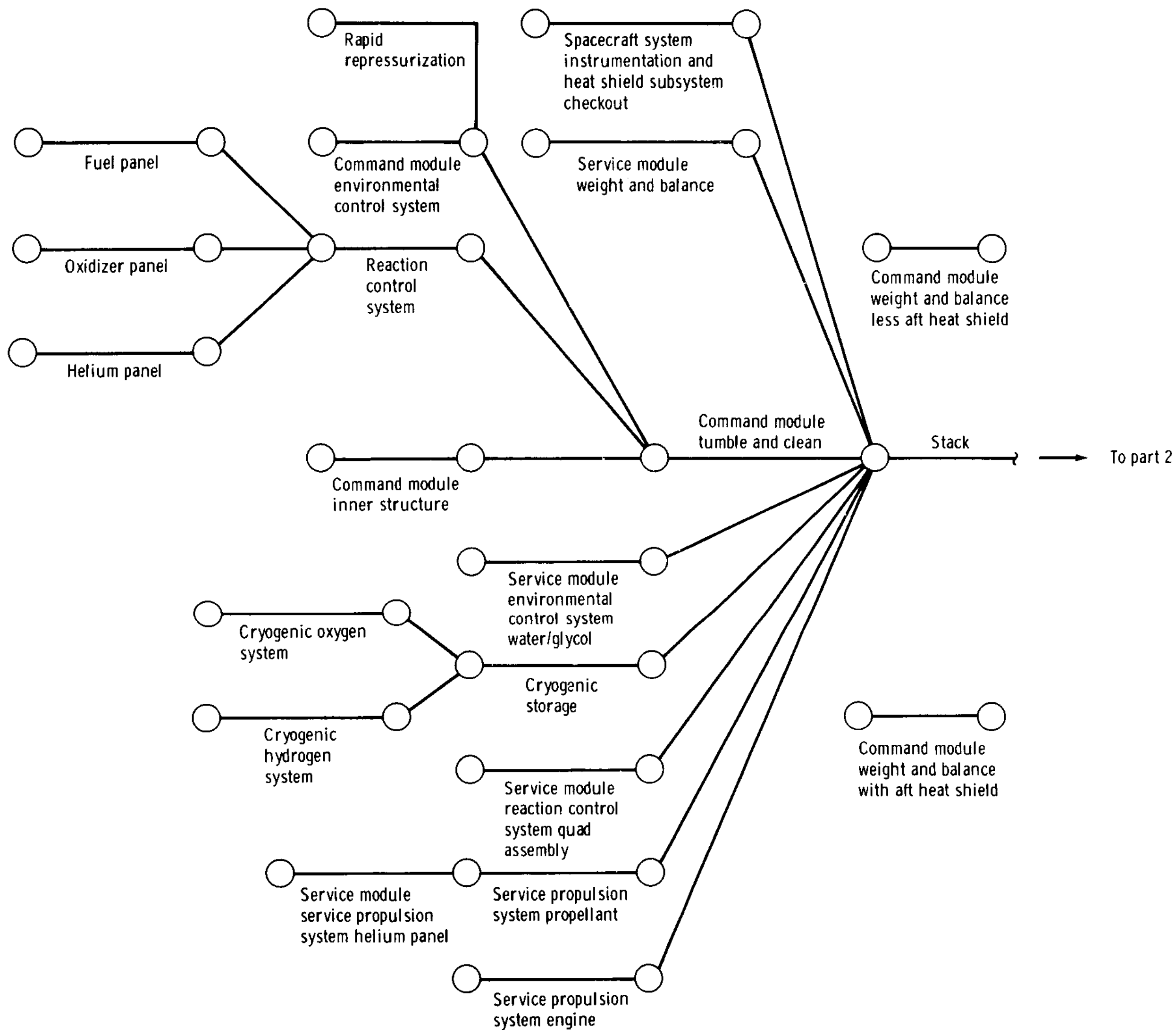
Destacking is the process of disassembling the stages or modules of a vehicle. Every destacking means possible vehicle damage, and retest is required to reestablish interface integrity. To maintain vehicle integrity in multimodule and multistage vehicles, destacking requirements should be minimized during the production acceptance test phase. The checkout flow and modification periods have to be optimized early to allow accomplishment of this objective. Too often, after the final acceptance tests of a vehicle in the factory, the vehicle was taken apart and reworked with the retest requirements passed on to the launch site, or the vehicle was destacked for shipment. At the launch site, some normal, noncontingent requirements may also dictate that the vehicle should be destacked. However, destacking should be avoided, and the total production test and checkout flow should result in a continuous buildup process terminating in a stacked vehicle. Test locales should be planned to minimize vehicle movement during checkout.

DESIRABILITY OF PREINSTALLATION ACCEPTANCE TESTS

A review of the Apollo preinstallation acceptance testing program disclosed that these tests often "crutched" inadequate vendor acceptance tests. The usual reason was that the test equipment, test procedures, test methods, and measurement systems used by the vendor generally differed from those used by the prime contractor. Under these conditions, if preinstallation acceptance tests are not conducted at the prime contractor's facility, problems will be encountered during vehicle-level tests. To resolve this problem, the vendor acceptance test equipment, procedures, and methods should be closely screened by the prime contractor and the responsible Government personnel to ensure that all requirements are acceptable. The vendor acceptance test would then serve as the preinstallation test.

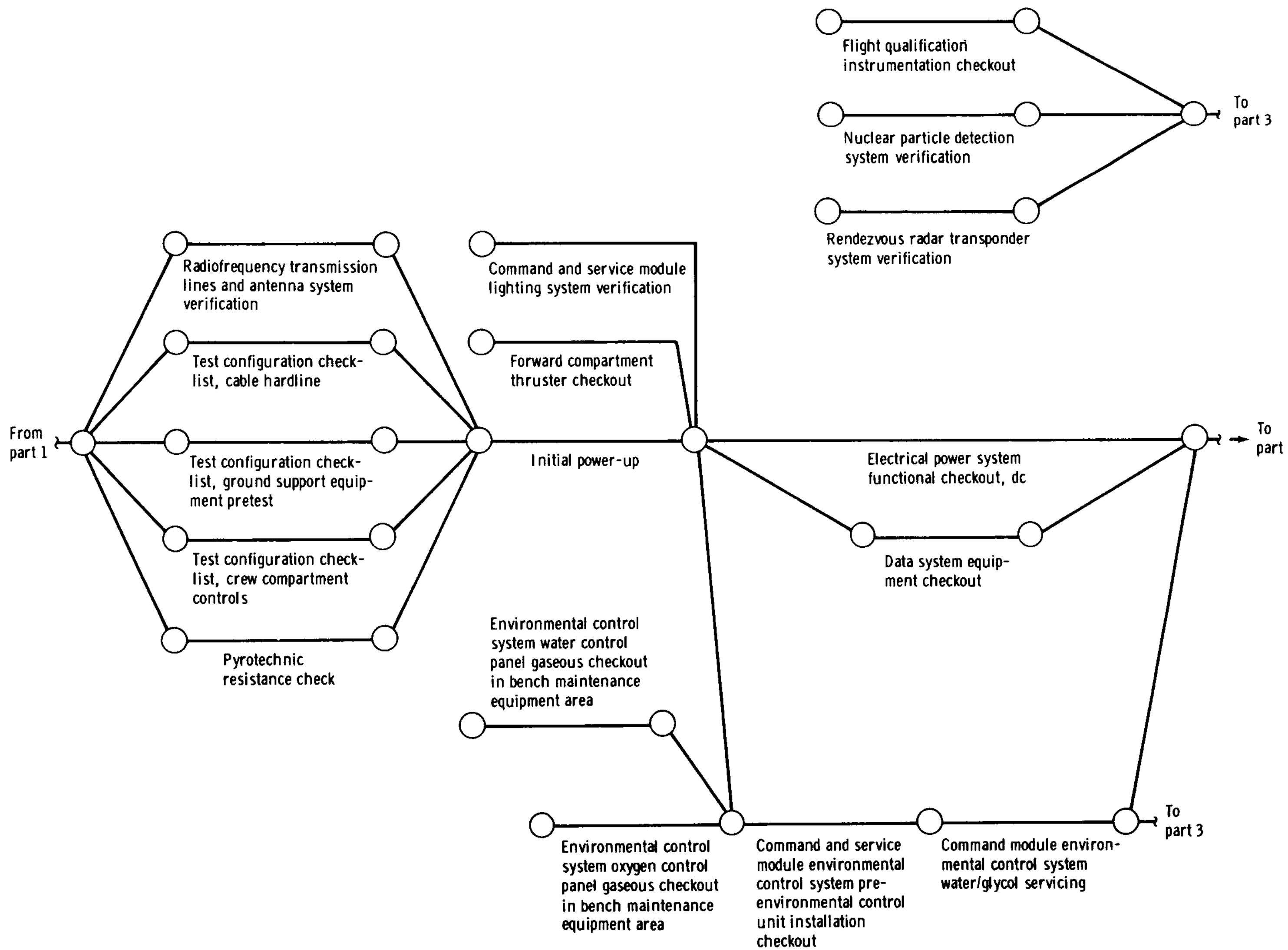
FACTORY OR FIELD TESTING

The purpose of launch-site testing is to reverify performance of the individual stages and modules, as received from the factory, through the performance of integrated systems tests. These tests should be followed by buildup of the space vehicle and the verification of all functional interfaces between the stages and modules, such as the command and service module (CSM)/launch vehicle interface. No new or first-time tests should be performed on the individual stages or modules at the launch site. A flow diagram of the typical acceptance test activities for the CSM is shown in figure 3. Typical launch-site test activities are shown in figure 4.



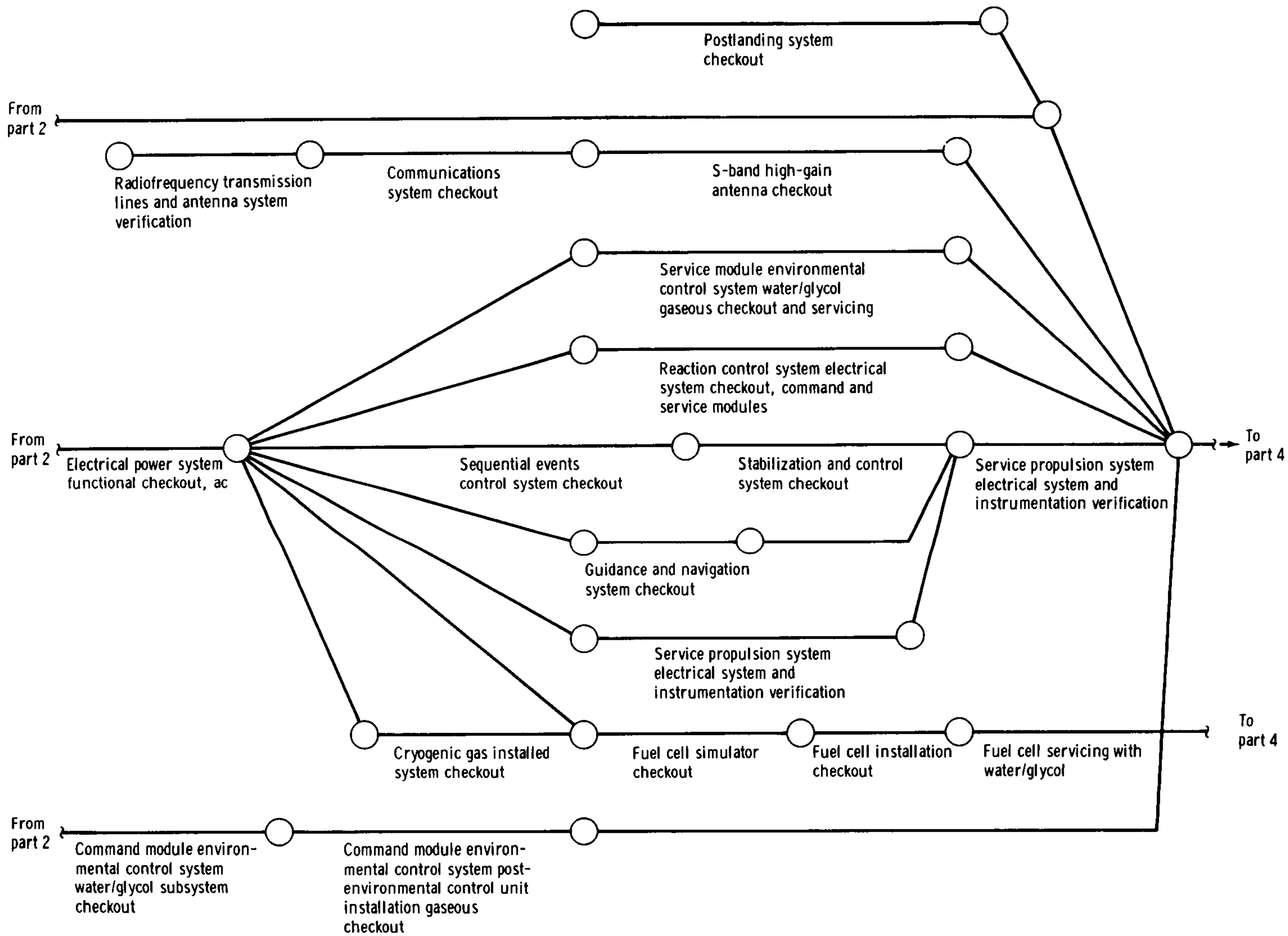
(a) Part 1.

Figure 3. - Factory checkout flow.



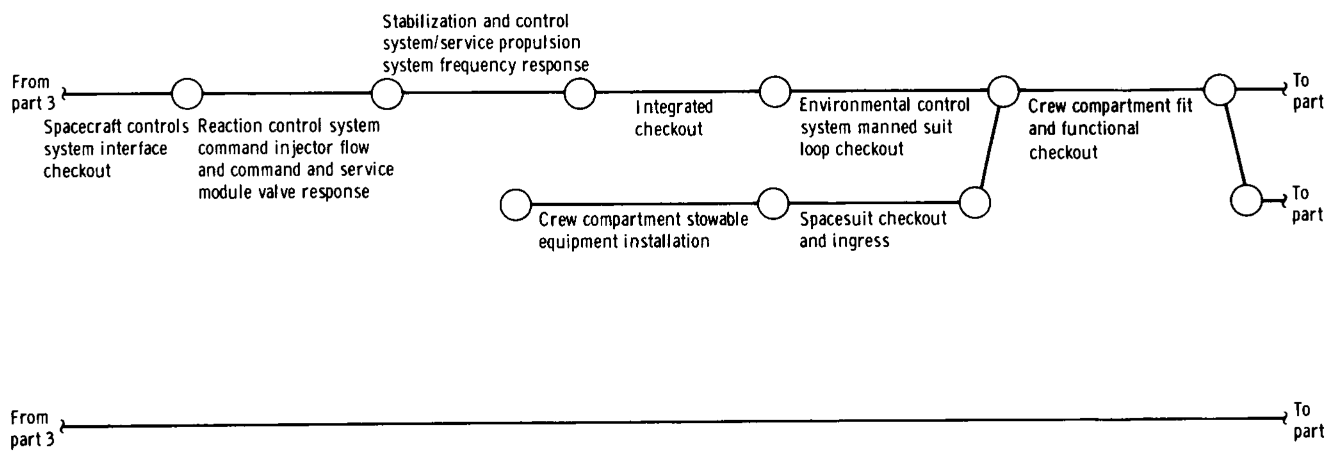
(b) Part 2.

Figure 3. - Continued.



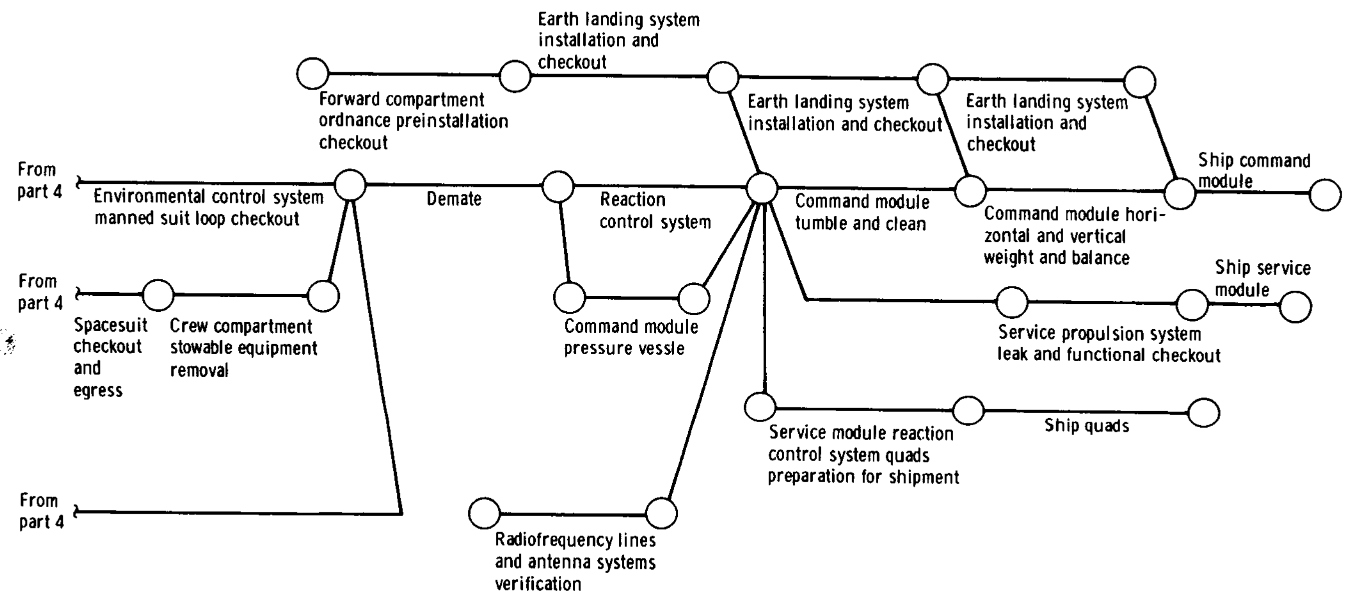
(c) Part 3.

Figure 3. - Continued.



(d) Part 4.

Figure 3. - Continued.



(e) Part 5.

Figure 3.- Concluded.

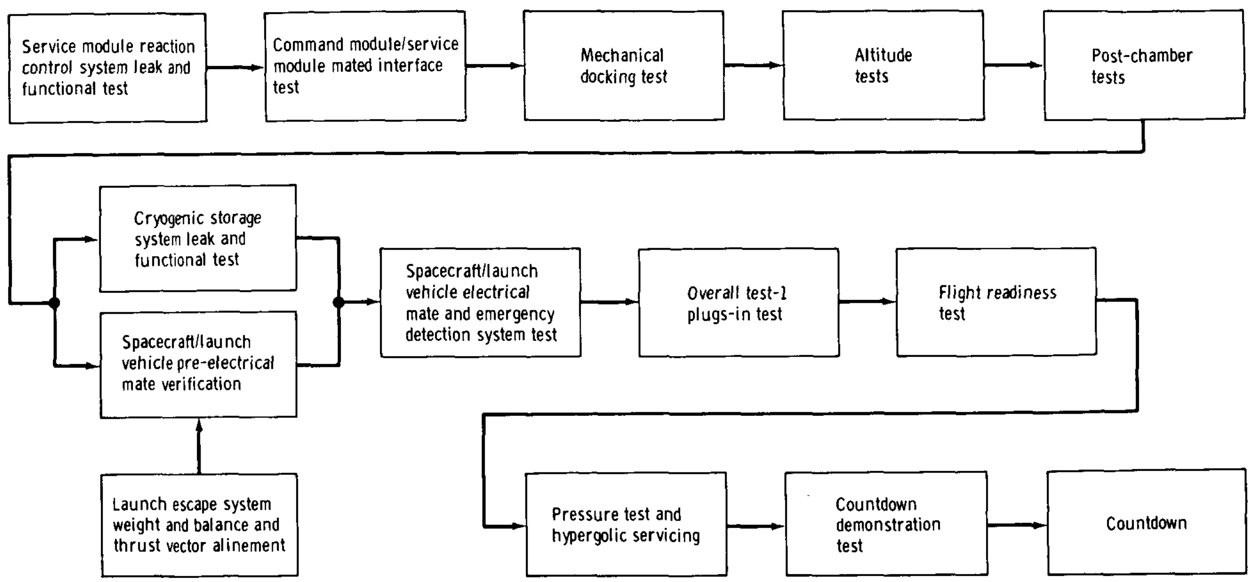


Figure 4.- The KSC test sequence.

Flight-readiness firings and initial environmental tests should meet factory or special-test-site requirements. Complete functional and environmental tests of the various Saturn launch vehicle stages occurred before delivery of the launch vehicles to the launch site. However, static firings were not conducted on Apollo spacecraft propulsion systems because of the unique considerations resulting from the use of engines requiring hypergolic propellants. These considerations were, primarily, that the propulsion systems were difficult to purge and clean, the propellant caused corrosion of system components, and the toxicity of the propellant presented a hazardous working condition.

Two different vacuum-chamber tests were conducted on the Apollo spacecraft. For economy, the chambers were installed at KSC to reduce the requirements for construction of special facilities at the prime contractor's plants and to allow the vacuum chambers to be used for follow-on programs. Hazardous tests of manned modules, such as vacuum-chamber altitude simulations, should be conducted late in the test flow. At that time, the spacecraft modules are closer to flight configuration and greater assurance of crew safety exists.

USE OF NONFLIGHT EQUIPMENT DURING CHECKOUT

In the Apollo Program, the use of nonflight equipment or substitute units during vehicle-level tests was a continuous source of discussion. These units were used when repeated testing or continuous cycling could be detrimental to critical flight items. For example, nonflightworthy reaction control engines were used for lunar module factory checkout. Substitute units may be required for use in place of sensitive electronic packages, especially those exhibiting a high change rate or a high failure rate. The same principle applies to guidance computer programs, or software, in which late availability could be a problem.

One argument against using nonflight hardware and software is that it may not represent the proper flight configuration. This is especially undesirable during a period in which change activity is high. This situation can be controlled with a rigid configuration management system that ensures change effectivity in the flight substitutes. Questions then will arise as to when in the test flow flight software should be used instead of test software and when substitute units should no longer be used. Apollo experience indicates that flight software can be incorporated into the spacecraft extremely late in the launch-site checkout flow, provided that rigorous means of verification and reverification by an independent source have been used.

DESIRABILITY OF PROPULSION SYSTEM FIRING TESTS

The requirement for stage- or module-level propulsion system firing tests, often called flight-readiness firings, was another debatable issue. Every stage of the Saturn launch vehicle was subjected to an acceptance firing. It has been stated that a vehicle-level firing test additionally serves as a good vibration test for all vehicle equipment. This was true for the launch vehicle stages because the vibration environment during ground firing was more severe than that encountered during flight. However, this was not true for all spacecraft propulsion modules because of the lower thrust levels of some engines. This issue must be settled early in subsequent programs so that the vehicles can be built and the test flow planned to accommodate an acceptance firing.

The Apollo lunar module ascent and descent engines were not capable of being fired at sea level conditions, and purging and cleanup requirements after firing of engines using hypergolic propellant would have decreased the confidence that the firing had produced. The Apollo service module engine also was not acceptance fired after installation because of the hypergolic considerations. However, production units were successfully fired during unmanned flights of both vehicles. An additional confidence firing of a nonflight production service module was performed. Satisfactory system performance was verified, but teardown of the system confirmed the existence of contamination and corrosion, thus reinforcing the decision not to perform ground firings of flight systems. Arguments against acceptance firings are the increased cost and the scheduling problems that would result.

VACUUM TESTING CONSIDERATIONS

In the Apollo Program, vehicle-level vacuum tests were conducted late in the test and checkout flow. An "all up" vehicle (a completely assembled CSM) was subjected to the vacuum environment to find faults that result from vacuum-induced expansion, and the complete environmental control system (ECS) was tested with the suited crewmen. Because vehicle-level tests were conducted, not all individual systems and equipment were previously exposed to a vacuum environment. It is recommended, however, that vacuum testing of specific systems and types of equipment be accomplished before vehicle-level testing to minimize the possibility of problems in the later tests and the resulting impact on schedules. As a minimum, the following categories of equipment should be individually tested in a vacuum environment.

1. Items for which additional confidence is desired, such as life-support systems equipment

2. Items that have marginal or questionable environmental sensitivity, such as electronic equipment packages containing soft potting

3. Items that would require destacking or removal of a major structure for their replacement

CREW EQUIPMENT STOWAGE TESTS

Manned spacecraft test programs should include crew equipment stowage tests at the factory to ensure the adequacy of storage space and to check accessibility and utility. Because crew equipment is generally one of the last items to be delivered, the requirement for these tests establishes firm goals for crew equipment delivery. The initial tests should be conducted by experienced crewmen to ensure that the stowage will be acceptable in the flight environment.

CHECKOUT OF REDUNDANT FUNCTIONS

Crew safety was enhanced by minimizing the number of single-point-failure possibilities in the Apollo spacecraft design. This was accomplished primarily by providing completely separate or alternate systems to perform the same function. If a mission function was critical, two identical primary paths were provided, and both paths usually operated simultaneously. Within each parallel path, additional series redundancy was usually provided when the paths contained critical parts and components. Parallel redundancy assured that a function was accomplished when required; series redundancy assured that a function would not be accomplished before it was required.

In addition to the primary mode, a secondary or backup mode was provided for very critical functions. The backup mode was generally a manual and more direct method of accomplishing the mission function; that is, it bypassed some of the devices that had to operate in each of the primary paths. The backup mode generally did not operate simultaneously with the primary mode, and redundancy may or may not have been incorporated.

An example is given for additional clarification. Escape-tower jettison was a mission function required in the manual launch sequence. The primary mode of tower jettison was ignition of the tower jettison motor and separation of the tower bolts. This was accomplished automatically by the mission sequencers. Full end-to-end parallel redundancy was provided from the initiating mechanism to the function-accomplishing mechanism. One of the parallel paths was called the primary path and the other the redundant path. The backup mode for tower jettison was initiated manually. A switch was actuated that ignited the launch escape motor and separated the tower bolts. This use of more than one relay, either parallel- or series-installed, provided circuit redundancy.

Three aspects of verifying proper operation of redundant functions and backup modes need to be considered; each usually requires a separate test and checkout method. The processes are as follows.

1. The primary and redundant functions[1] are tested in three steps in the spacecraft. Each parallel path is tested individually, end to end, and the parallel paths are tested simultaneously in the third step. This three-step checkout does not test the backup mode.

2. The backup mode is tested in one step, end to end.

3. The previously described end-to-end tests verify the open (permissive) position of the redundancy.[2] To verify the closed position, each item is checked separately. This is a relatively easy task if test points are provided between each item. These test points, however, are frequently not designed into the equipment for spacecraft-level checkout, and a true test can only be made during component fabrication or assembly and checkout of the equipment before installation in the spacecraft.

Adequate testing at the factories constitutes complete verification of all redundant functions (case 1) and all backup modes (case 2) and a partial verification of redundancy (case 3). The redundancy verification not accomplished at a spacecraft level must be identified. Checkout of the redundant functions at the launch site should be accomplished as late as is practical in the spacecraft flow and should include all the redundant and backup modes that can be assessed.

INTEGRATED SUBSYSTEM CHECKOUT

The initial lunar module checkout philosophy was to verify each subsystem individually before verification of the next subsystem. This process was extremely long and costly. To save factory test time and to use the GSE hardware and software capabilities to their fullest advantage, an integrated subsystem checkout concept was implemented. This concept allowed several subsystems to be under test simultaneously under overall control of a master test document. With this method, when checkout of one subsystem was constrained because of an anomaly, the checkout flow for the remaining subsystems could continue. This philosophy did require considerable planning

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[1]The term "primary and redundant functions" refers to the operation of both paths of a pair of similarly constructed primary paths used to accomplish a single mission function.

[2]The term "redundancy" refers, in this sense, to the provision of two or more identical parts or components used in a primary or redundant function or backup mode path.

effort to optimize the testing, troubleshooting, repairs, and replacements and to reduce the number of test constraints. The end result was that the spacecraft delivery milestones were met with substantially less test time on the spacecraft than under the previous system of testing each subsystem independently.

CHECKOUT TOLERANCES

Satisfactory performance of the ECS was difficult to verify during factory checkout of the first manned vehicle. An investigation revealed that the tolerance values being used for vehicle-level tests were those specified by the supplier for the individual components. The results were that many failures were being reported, components were being replaced unnecessarily, and the resulting retests were severely hampering the checkout flow. The tolerance being used did not take into account test configuration and GSE differences that did not permit measuring to these tight tolerances. Consequently, the tolerances were adjusted to the mission requirements and then narrowed from these values by a root-sum-square technique that accounted for GSE inaccuracies and spacecraft hardware measurement tolerances. Subsequent vehicle checkout progressed satisfactorily and no flight failures that could be attributed to checkout tolerances being too broad have been observed.

CONCLUDING REMARKS AND RECOMMENDATIONS

Although Apollo test and checkout methods were based, to a large extent, on experience gained from previous programs, many additional lessons were learned as the Apollo Program progressed. Some of the more significant aspects of Apollo acceptance testing and preflight checkout experience have been discussed, and recommendations for future programs are summarized here.

1. The Apollo test documentation method of combining requirements and specifications into a multiple-spacecraft document is practical and is recommended for future use.

2. Rigidly controlled procedures are recommended for the incorporation and testing of hardware and software changes made during the acceptance testing and checkout process. In addition, vehicle/support equipment configuration control and documentation control must be strictly adhered to during all test periods.

3. A comprehensive retest plan is required during the early stages of checkout, delineating requirements for demonstration of vehicle integrity after replacements, modifications, repair, et cetera. Retention of the Apollo philosophy as a baseline for establishing retest requirements is recommended.

4. Requirements for destacking of multimodule or multistage vehicles should be held to a minimum during the production acceptance-test phase.

5. Consideration should be given to deleting preinstallation acceptance tests in favor of vendor acceptance tests.

6. Where feasible, new or first-time tests should not be performed on individual stages or modules at the launch site; these tests should be conducted at the factory.

7. The use of nonflight equipment for checkout should be discouraged. When substitutes are required, the design should duplicate the functional characteristics of the flight items.

8. Where feasible, at least one propulsion system firing should be conducted on a flight-configured stage or module as a proof of the production, test, and checkout processes.

9. Vacuum testing should be performed at the component (black box) or highest practical level of assembly on all flight equipment susceptible to failure under vacuum exposure. This should be performed before vehicle vacuum testing.

10. A crew equipment stowage test should be conducted at the factory.

11. Complete verification of all redundant functions and backup modes should be accomplished at the factory, and, to the extent possible, component redundancy should be verified. The redundancy verification not accomplished at the spacecraft level must be identified. Checkout of the redundant functions at the launch site should be accomplished as late as is practical and should include all redundant and backup modes that can be assessed.

12. Apollo factory experience indicates that parallel checkout of selected spacecraft subsystems is a practical consideration and can decrease overall checkout time.

13. Checkout tolerances should be based on mission requirements and should consider the accuracy of both the spacecraft and ground support equipment measuring systems.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, January 23, 1974
914-11-00-00-72

APPENDIX A

GLOSSARY

All-up vehicle - A completely assembled module

Bench-level testing - Testing performed on a component basis or module basis outside the spacecraft

Failure mode and effects analysis - Analysis of failure modes and their effect on systems and on mission performance

Flight Readiness Test - Last major test conducted before the Countdown Demonstration Test to verify that all spacecraft systems are in a state of flight readiness; includes systems compatibility during abort modes and during a normal mission

Functional mode - The terminal activity or indication that is the end result of a transmitted signal or initiating force

Functional path - One or more routes by which a transmitted signal or initiating force can be directed to accomplish a desired activity or indication

Interface integrity - Completeness of mechanical, electrical, and functional mate of two or more modules or stages

Software - Computer programing, test procedures

APPENDIX B

APOLLO PROGRAM DIRECTIVE NO. 26B

OFFICE OF MANNED SPACE FLIGHT
PROGRAM DIRECTIVE

M-D MA 1400.135 (Project)

DATE December 8, 1970

APOLLO PROGRAM DIRECTIVE NO. 26B

TO : DISTRIBUTION

FROM: Rocco A. Petrone
ROCCO A. PETRONE
APOLLO PROGRAM DIRECTOR

SUBJECT: Addendum 1 to Apollo Program Directive No. 26B
Preparation of Test and Checkout Plans and Procedures at KSC

I. PURPOSE

The purpose of this addendum is to require that proper levels of approval for hazardous test and checkout of troubleshooting procedures be identified in KSC Operations Directives.

II. Hazardous Operations Approval Requirements

KSC Operations Directives shall identify approval levels for tests or troubleshooting procedures involving hazardous operations or test or troubleshooting procedures not previously verified at the launch or factory sites.

III. Implementation

The requirement established by this addendum is effective immediately and implementation is applicable to all missions. Copies of implementing instructions shall be forwarded to MA.

APOLLO PROGRAM DIRECTIVE NO. 26-B
MA 009-026-1B

TO : DISTRIBUTION

FROM: Samuel C. Phillips
APOLLO PROGRAM DIRECTOR

SUBJECT: Preparation of Test and Checkout Plans and Procedures at KSC

I. PURPOSE

This Program Directive covers the preparation and control of test and checkout plans and procedures for the preparation and launch of Apollo-Saturn space vehicles at KSC.

II. SCOPE

This Directive defines the requirements, responsibilities and inter-center coordination necessary to the development, revision and execution of test and checkout plans and procedures for the preparation and launch of Apollo-Saturn space vehicles at KSC.

III. RESPONSIBILITY

The Directors of KSC, MSC, and MSFC are responsible for taking action as necessary to implement this Directive. Responsibilities assigned in this Directive may be delegated except in instances where the delegation of responsibility shall be no lower than the level specified herein.

IV. TIME COMPLIANCE

This Directive is effective for all subsequent Apollo/Saturn missions except that the use of standardized names for KSC Test and Checkout Plans and Test and Checkout Procedures shall be effective for AS-205 and AS-503 and subsequent missions.

V. IMPLEMENTATION

A. The Manned Space Flight Centers shall prepare directives to implement the responsibilities assigned herein and submit copies to Apollo Program Director.

B. Any inter-center problem arising in the implementation of this Directive which cannot be resolved shall be brought to the immediate attention of the Apollo Program Director.

VI. GENERAL

A. Development organizations (MSFC and MSC) are responsible for defining specific test and checkout requirements that must be performed on flight vehicles at the factory prior to acceptance and at the launch site prior to flight. Test and checkout requirements to demonstrate the performance of ground support equipment provided by the development organization which is associated with factory acceptance and launch site preparation shall be included. The test and checkout requirements shall clearly define what is to be tested. Test methods, hardware configuration, test sequence and other constraints shall be identified to the extent necessary to assure attainment of test objectives, protect hardware from damage and provide for the safety of personnel.

B. The combined factory and launch site test and checkout requirements shall provide an integrated flow of testing. The objective of the integrated test flow shall be to permit verification of the functional performance of essential systems and their integration into the space vehicle without unnecessary repetition of factory level testing. To the extent practicable, the overall test flow shall permit correlation of data between factory and launch site testing for critical flight hardware components.

C. Development organizations are responsible for providing test specifications and criteria or limits including redline values and associated configuration constraints by which to judge acceptable performance of flight hardware and ground support equipment furnished by the development organization.

D. The development organizations use different titles and formats for Test and Checkout Requirements and Test Specification and Criteria documents. At the earliest time convenient without republishing existing documents these shall be renamed as the Test and Checkout Requirements Document and the Test and Checkout Specifications and Criteria Document. If desired, the later document may be included as a part of the Test and Checkout Requirements Document.

E. MSC and MSFC shall prepare and approve Test and Checkout Requirements and Test and Checkout Specifications and Criteria Documents for the flight vehicles and GSE which they develop. Approved documents shall be provided to the launch organization (KSC) no later than four months prior to delivery of flight vehicles to the Cape.

F. MSC is responsible for preparing flight crew procedures for use on launch day and during flight. These procedures and changes thereto shall be made available to KSC for use in preparing test and checkout procedures involving flight crew participation.

G. The above documentation provides the framework within which the launch organization prepares test and checkout plans for integrating all test activities at the launch site and develops detailed test and checkout procedures for each test.

VII. TEST AND CHECKOUT PLAN

*A. A test and checkout plan shall be prepared by KSC. It shall provide an outline for accomplishing center test and checkout requirements at the launch site and shall include any additional test requirements necessary to verify launch facility, interface and compatibility with the Mission Control Center - Houston and the Manned Space Flight Network, and launch crew readiness or satisfy range and safety requirements.

B. The following information shall be included:

1. A flow plan designating the sequence of tests to be performed.

2. Identification of the facilities involved in the overall test flow.

3. Specific outlines for each test including the following:

a. Test title and procedure number.

b. Test objectives.

c. Test location and facility.

d. Test description in sufficient detail to define the procedure in outline form.

e. Flight hardware and GSE configuration requirements.

f. Software requirements.

*Denotes change.

g. Significant support requirements.

h. Identification of any hazardous operations.

i. Safety requirements including any special equipment, personnel, procedures or training required for test.

j. Identify organizations outside of KSC that will be involved.

k. A cross reference to the development center test requirements where applicable.

4. A detailed list of deviations from development center test requirements.

VIII. TEST AND CHECKOUT PROCEDURES

A. Test and Checkout Procedures shall be prepared by KSC. A Test and Checkout Procedure shall define the detailed step-by-step sequence of events in a specific test and shall be generated for each test during preparation and launch of flight vehicles.

B. KSC and contractor responsibilities and interfaces in the preparation, revision and execution of Test and Checkout Procedures shall be clearly defined by a KSC Management Instruction or other suitable document approved by the KSC Director. This document shall designate the official, at an appropriately high level in the KSC organization, who is responsible for determining which tests are hazardous.

C. MSC and MSFC may exercise an option to review Test and Checkout Procedures as deemed necessary. Any recommended changes shall be provided to KSC no later than 15 days prior to the start of the test.

D. MSC and MSFC shall establish a mechanism to process launch site recommended changes in factory testing.

E. The following guidelines shall be used in the preparation, revision and execution of KSC test and checkout procedures.

1. Factory or test site test and checkout procedures which have been approved by the development organization shall be used as a baseline in the development of Launch Site Test and Checkout Procedures. Whenever possible, Test and Checkout Procedures written for use in the factory

will be modified for use at the launch site to fit unique facility requirements, safety considerations, integrated space vehicle test requirements and to meet objectives in the test and checkout plan.

2. MSC is required to deliver approved flight crew procedures to KSC at least 40 days prior to a test or checkout operation involving the flight crew (See paragraph IX, B-2). Flight Crew Procedures as approved and published by MSC shall be used by KSC when applicable in preparing those test and checkout procedures involving the flight crew. In any cases where incompatibility between test and checkout procedures and flight crew procedures exists, KSC will obtain MSC approval of the Test and Checkout Procedure.

3. All Test and Checkout Procedures involving hazardous operations shall contain or provide specific reference to written instructions for identifying emergency situations, safing of hardware and implementing emergency actions required to evacuate or safeguard personnel and combat or limit the extent of the damage should an emergency arise.

4. Test and Checkout Procedures shall be standardized in regard to the following items.

   a. Major policy and procedure matters regarding preparation, review, approval and change cycle.

   b. Control, approval level and documentation of troubleshooting during the conduct of Test and Checkout Procedures.

   c. Extent of quality control participation and sign off during execution of Test and Checkout Procedures.

   d. Extent of safety and medical organization participation. (See NMI 8900.1)

   e. Recording and approval level for deviations encountered during implementation of Test and Checkout Procedures.

   f. Policy concerning multiple effectivity of Test and Checkout Procedures.

   g. Inclusion or exclusion of preparation steps in Test and Checkout Procedures.

h. Recording of OIS channels during execution of Test and Checkout Procedures.

i. Appropriate use of warning and caution notes.

*5. Prior to publication of a test and checkout procedure (TCP) for: (a) operational checkout of flight hardware; (b) functional verification and operational control of GSE; and (c) operational instructions to service, handle, and transport end item flight hardware during prelaunch and launch operations; it shall be approved by the KSC Safety Office for assurance that operations are compatible with KSC Safety criteria KMI 1710.13 and use appropriate safety personnel, techniques, and equipment.

*6. Prior to publication of a technical procedure to: (a) authorize work, (b) provide engineering instructions; and (c) establish methods of work control; and involving hazardous operations, it shall be approved by the KSC Safety Office for assurance that operations are compatible with KSC safety criteria KMI 1710.13 and use appropriate safety personnel, techniques and equipment.

7. Test and checkout procedures involving human test subjects shall be coordinated with medical personnel for assurance that potential risks to the health of test subjects are minimized. (See NMI 8900.1)

8. Test and Checkout Procedures shall be provided to the KSC Launch Vehicle or Spacecraft Quality Surveillance Division for review and use in preparing for participation in test and checkout operations.

9. Test and Checkout Procedures and changes thereto for tests involving flight crew participation shall have signature approval of MSC.

10. Approved Test and Checkout Procedures shall be distributed one month prior to the date of the test.

11. A Test and Checkout Procedure control system shall be established which places positive control over changes subsequent to the distribution of approved copies to the test team. Only those changes in spacecraft, launch vehicle or space vehicle test and checkout procedures which will improve safety or are mandatory because of late changes in hardware configuration shall be approved in

*Denotes change.

the last seven calendar days before scheduled start of a test unless approved by the following organizational level for the test indicated.

a. Launch Operations Manager

(1) Flight Readiness

(2) Countdown Demonstration

(3) Countdown

b. Test Supervisor

(1) CSM or LM altitude chamber tests in MSOB

(2) CSM or LM final integrated systems test in MSOB

(3) CSM or LM integrated test in VAB or on pad prior to mating with space vehicle

(4) L/V overall tests 1 and 2 in VAB or on pad

(5) S/V overall tests 1 and 2 in VAB or on pad

(6) S/C or L/V propellant loading on pad

(7) S/V simulated flight in VAB or on pad

(8) Pyrotechnic installation in VAB or on pad

12. Revisions to Test and Checkout Procedures shall be provided to test team members at least 48 hours in advance of the start of the test. Waivers to this requirement shall be approved at the organizational level established by the KSC Director except that this approval cannot be delegated lower than specified in VIII E-11 above for the tests indicated.

13. Prior to initiation of a test, briefings shall be conducted for all key members of the test team to review the sequence of test activities, the Test and Checkout Procedures and any hazardous operations or emergency procedures.

14. Prior to initiating a test, a review shall be made of all open work recorded against the hardware to be tested. A determination shall be made that the hardware (including GFE) is properly configured and that the Test and Checkout Procedure, Flight Crew Procedure and hardware are compatible. This determination shall be recorded and approved by KSC and contractor organizations involved in the test. The procedure for recording and the level of approval shall be as specified by the KSC Director. For spacecraft hardware tests involving flight crew participation, this determination shall have signature approval of MSC.

15. Approval to initiate non-hazardous tests shall be at the organizational level established by the KSC Director.

16. Approval to initiate any test involving a hazardous operation shall be at the organizational level established by the KSC Director in accordance with VIII E-11 above.

17. The Director, MSC, and the Director, MSFC, shall delegate the authority either to KSC or to the appropriate official of their own organizations to approve real time deviations to Test and Checkout Procedures involving compromise in test and checkout requirements.

18. Changes in flight hardware configuration, test and checkout requirements, or test and checkout specifications and criteria shall be approved by MSC and MSFC for the spacecraft and launch vehicle respectively.

19. The flight crew shall use Test and Checkout Procedures when participating in flight hardware tests at the launch site. Flight crews shall come under KSC control during the time they are actively participating in tests of flight vehicles except that the flight crew may take any action necessary for its safety.

20. Deficiencies encountered by the flight crew while participating in KSC tests shall be recorded and dispositioned using the same documentation system as that used by the test team.

21. KSC shall make an analysis of Test and Checkout Procedures deviations subsequent to completion of major tests for the purpose of reducing deviations in subsequent Test and Checkout Procedures.

22. Tests involving hazardous operations shall not be conducted unless communications are adequate to support emergency operations.

IX. CENTER RESPONSIBILITIES

A. MSFC and MSC are responsible for:

1. Preparing an appropriate document which assigns responsibility for functions and actions contained herein.

2. Establishing and maintaining test and checkout requirements, test and checkout specifications and criteria, and launch mission rules inputs which are necessary to assure test and checkout and flight readiness.

3. Providing signature approval on KSC test and checkout plans.

4. Approving deviations or waivers to test and checkout requirements, test and checkout specifications and criteria, and launch mission rules specified in IX A-2 above.

5. Participation in preparation, revision and execution of KSC Test and Checkout Procedures in accordance with Section VIII.

6. Assuring that adequate testing is being accomplished without unnecessary overlap and duplication.

7. Providing signature approval on KSC criteria for determining hazardous operations.

B. MSC is responsible for:

1. Advising KSC in writing of tests requiring flight crew and/or flight control personnel participation.

2. Providing approved flight crew procedures to KSC at least 40 days prior to a test or checkout operation involving the flight crew.

3. Providing signature approval on KSC Test and Checkout Procedures involving flight crew participation.

4. Providing signature approval on pre-test reviews of spacecraft hardware (including GFE) and Test and Checkout Procedure compatibility for those tests involving flight crew participation.

C. KSC is responsible for:

1. Preparing an appropriate document which assigns responsibility for functions and actions contained herein.

2. Developing test and checkout plans as defined in Section VII at least one month prior to delivery of flight hardware for each mission.

3. Securing MSC and MSFC signature approval on test and checkout plans and changes thereto before these documents are approved or implemented.

4. Preparing, revising and executing Test and Checkout Procedures in accordance with Section VIII.

5. Providing Test and Checkout Procedures to MSC and MSFC one month prior to the start of a test and assuring expeditious distribution of changes thereto.

6. Securing MSC signature approval on Test and Checkout Procedures and changes thereto and the pre-test reviews of spacecraft hardware and test and checkout procedure compatibility for those tests in which the flight crew has a requirement to participate.

7. Assuring that MSC flight crew and flight control personnel are integrated into the KSC test team for those tests in which they have a requirement to participate.

8. Developing criteria for determining hazardous operations and securing signature approval of MSC and MSFC.

9. Making final determination that Test and Checkout Procedures are adequate, safe and in accordance with development organizations test and checkout requirements, test and checkout specifications and criteria, flight crew procedures and launch mission rules.

10. Obtaining deviations and waivers from development organizations test and checkout requirements, test and checkout specifications and criteria and launch mission rules which will not be fulfilled.