PART E6

APOLLO SPACECRAFT PROGRAM MANAGEMENT SYSTEMS

The various organizational relationships and the management philosophy for Apollo are defined in reference 1. This document defines the relationship and functioning of the various organizational elements which have been described in Parts E4 and E5 of this Appendix. In addition, there are several other documents which provide implementing details concerning the management control systems and their intended operation.

A general understanding of the management systems which are being used and their relationship to the program progress is helpful in determining or appreciating the extent of the review which is applied to all phases of the program throughout design, manufacturing, test, checkout, and operation.

It is also considered important to recognize that some of the review and control systems are primarily concerned with the entire scope of a module program and that others concentrate on individual modules by serial number.

The systems which have been implemented by MSC are generally similar for both the CSM and the LM. Due to the nature of this review, the CSM only is considered and all subsequent reference to a vehicle means the CSM or more particularly the service module.

There are three management systems which directly impact all CSM's at various points in time:

(a) Design Reviews

(b) Configuration Management

(c) Readiness Reviews

Throughout the entire management process the Reliability and Quality Assurance system maintains a continuing surveillance of all problems.

DESIGN REVIEWS

The contractor initiates the design phase of the contract based upon the general specifications and the performance requirements established by the ASPO. These requirements and broad specifications are developed by the MSC technical organization and approved by the ASPO prior to the contractor initiating activity.

Preliminary Design Review

The general requirement is for a Preliminary Design Review (PDR) to be conducted on the CSM when the design concept has been determined by the contractor and prior to the start of detail design. The ASPO Systems Engineering Division normally organizes and conducts these reviews which are chaired by the Apollo Spacecraft Program Manager. Various subsystems may reach a design concept stage earlier than others and a series of PDR's may be conducted. The result of the PDR is to establish the design requirements baseline from which engineering control can be exercised. Upon the completion of the review, the ASPO manager authorizes Part I of the end-item specification to be inserted in the contract, along with any necessary design modifications.

Critical Design Review

The Critical Design Review (CDR), also organized and conducted by ASPO Systems Engineering Division and chaired by the ASPO Manager, is held when the contractor has released or completed between 90 and 95 percent of the engineering. At this point there is sufficient information for the ASPO and the appropriate subsystem managers to adequately review the engineering and to determine if the objectives of the design concept have been achieved. Again, because the engineering for different subsystems is not all completed at the same time, a series of CDR's may be conducted. At the completion of the CDR a drawing baseline is established and the strict Configuration Control System is implemented.

CONFIGURATION MANAGEMENT

A primary document, in addition to reference 1 which defines the Configuration Management Control System, is the "Apollo Spacecraft Program Configuration Management Manual," (ref. 2). This document details the various change control levels, defines the categories of change, and establishes the membership of the various boards and panels which are involved. Figure E6-1 depicts this total relationship among the five change control levels. This document contains the detailed instructions which are necessary to implement the intent of the "Apollo Configuration Management Manual" as modified by the MSC Supplement No. 1 (ref. 3).

As shown by figure E6-1, there are actually five functioning levels of change control for the CSM. The Configuration Control Board (CCB), Level II, is responsible for the CSM, LM, and affected subsystems.

The Chairman of the CCB is the Apollo Spacecraft Program Manager; and the ASPO Managers for CSM, LM, the Experiments and GFE, the Assistant Program Manager for Flight Safety, and the MSC Directors of the

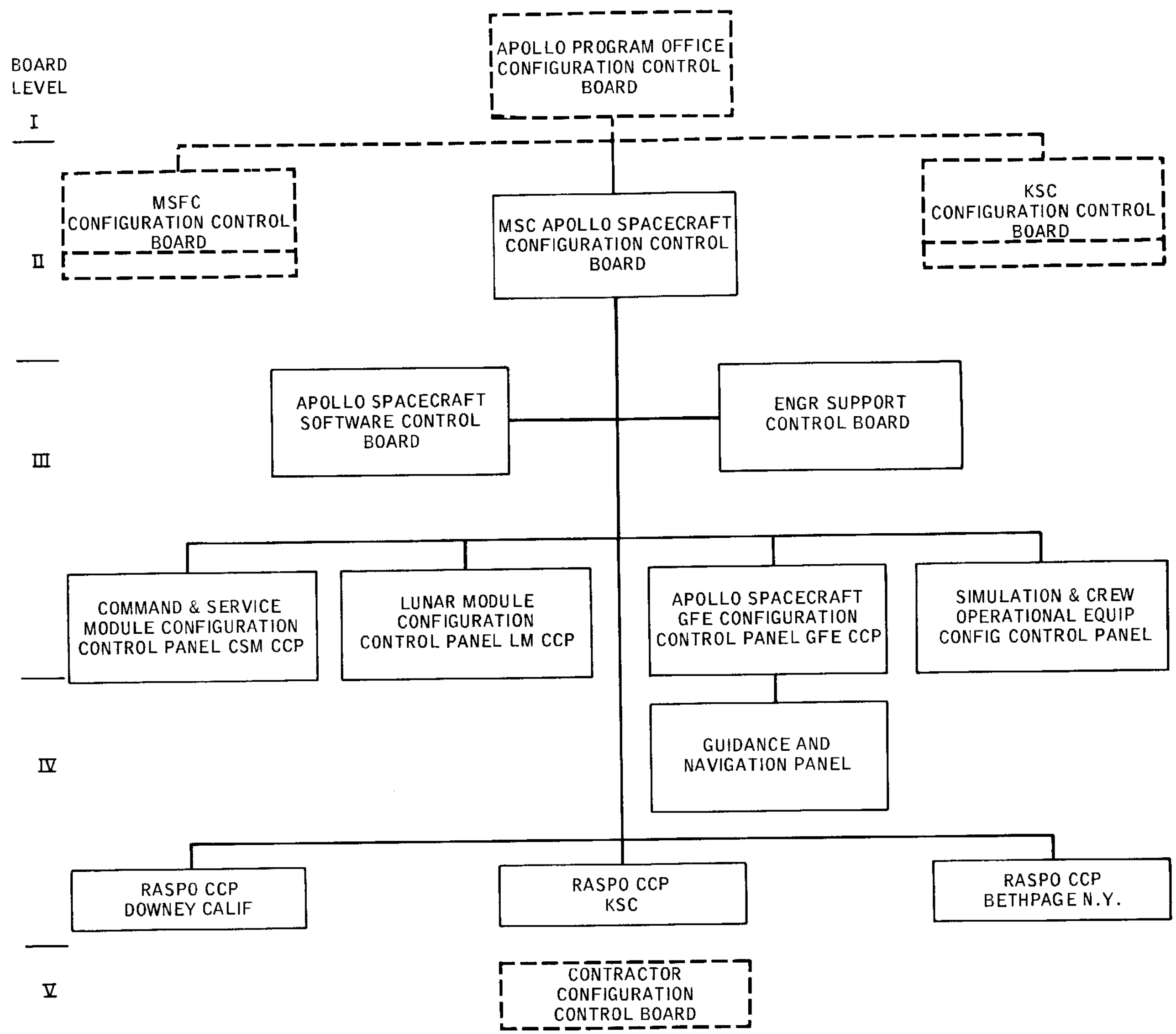

Figure E6-1.- Configuration Control Boards - Apollo Spacecraft Program.

five technical Directorates are principal members. The CCB is responsible for approval or disapproval of changes in the following major categories:

(a) Changes which affect an interface among two or more Configuration Control Panels (CCP).

(b) Changes which affect spacecraft mass properties.

(c) Change resulting in contract cost increases in excess of $300,000.

(d) Changes which affect end-item delivery dates.

It should be noted that change control is established for more than merely hardware or specification baselines. Also included are software items, such as mission timeline, math models, consumables, and schedules.

Configuration Control Panels (CCP) are established at Level III by the authority of the CCB Chairman and are designated as the approving authority for all Class I changes not designated for CCB action. Class I changes are defined in general as those affecting the specification, performance, cost, quality, safety, or interchangeability. Configuration Control Panels are established for the CSM, LM, and GFE. The CSM CCP is chaired by the ASPO Manager for CSM. Panel membership is obtained primarily from the same organizations as indicated for the CCB; however, the members are Division Chief level or designees rather than Directors.

The Level IV CCP is at the Resident Apollo Spacecraft Program Office (RASPO) at Downey. This panel is chaired by the Resident Manager. Generally, the panel can approve changes which concern test procedures but not hardware configuration. An exception to this is made during final checkout of a specific vehicle or during field test or launch preparation. These are classed as compatibility or make-operable changes, are restricted to single modules only, and must be reported to the CSM CCP within 24 hours.

A fifth level of change control exists because all changes whether Class I or Class II must go through the North American Rockwell (NR) CCB. This board is chaired by the NR Program Manager. It approves all Class I changes for submission to the appropriate NASA authority as previously defined and has the authority to approve Class II changes for implementation. The definition of Class I and Class II changes is that contained in ANA Bulletin 445 (ref. 4) which is considered to be a standard reference. Some subsequent modification of ANA 445 occurred during the course of the NR contract. However, the effect of these modifications or clarifications was to make the procedures and definitions more restrictive. It is noted that all Class II changes which are approved by the contractor are submitted to the RASPO for information. This provides an opportunity for review. Also, the NR control system is such that each Class II item is picked up and reported to R&QA. Class II changes include those not defined as Class I.

Although the CCB may be concerned with a change to a specific vehicle, in most instances the changes involve all of the remaining vehicles to be manufactured or which have not flown. That is, a major part of the effort of the CCB is devoted to assuring that the overall configuration is appropriate and that the procedures are compatible with all elements of the system. In general, the CCB is concerned about the configuration of the basic CSM. Readiness Reviews, which are discussed in the following section, are concerned with the exact configuration of a specific CSM.

With regard to subcontracts like that for the oxygen tanks, there is actually an additional level of configuration control by the Beech Aircraft Corporation. Their Configuration Control Board reviews all changes, both Class I and Class II. Class I changes are sent to NR for processing through the system and Class II changes may be approved by Beech for implementation. In actual practice there are only a few Class II changes and all of these are sent to NR for information and recorded in the system.

READINESS REVIEWS

The Readiness Reviews are conducted for each specific vehicle. These reviews are concerned with the manufactured subsystems that have been assigned to a specific CSM.

Customer Acceptance Readiness Reviews

The basic objective of the Customer Acceptance Readiness Review (CARR) is to evaluate the readiness of the CSM for delivery to KSC for launch preparation. The CARR Plan for Apollo command and service modules was revised in January 1969. This plan is referenced in the Apollo Spacecraft Program Configuration Management Manual (ref. 2) and has generally been applicable throughout the Apollo Program. The plan defines the detailed requirements for preparation of documentation, subsystem reviews, items for review and general procedures. Definition of the review teams, their composition, function, and tasks are also contained in the CARR Plan.

A complete CARR for a specific CSM is conducted in three phases:

(a) Phase I - To be conducted by the ASPO immediately prior to the initiation of installed subsystem checkout of the assembled CSM to identify constraints of subsystem tests. This includes firm identification of constraints to system tests.

(b) Phase II - This phase was a formal review until changed by ASPO letter of January 28, 1969, which authorized the RASPO-Downey to approve the start of CSM integrated test by the contractor.

(c) Phase III - Conducted by the Director, MSC, immediately prior to shipment to identify constraints to acceptance/shipment. It is a review of additional data from Phase I.

Systems Summary Acceptance Documents (SSAD) are compiled and used by Government and contractor subsystem review teams in the Phase I CARR. There are 44 of these documents prepared to cover the subsystems contained in the launch escape system, command module, service module, and the spacecraft-LM adapter (SLA). Of these, 14 involve the service module (SM) and there are separate documents for the environmental control system and the electrical power system and wiring, which include the cryogenic oxygen tanks.

SSAD books become the complete and official historical documents for each specific CSM subsystem. Included in the books are specific signed statements from both the responsible contractor engineer and the NASA Subsystem Manager certifying the readiness of the specific subsystem for the particular phase which is being reviewed.

The Phase III CARR is concerned only with documented changes since Phase I. This concept provides a means of concentrating on only those items which are different from the last review and avoids the effort which would be necessary to conduct each review from the beginning of the CSM history.

At the completion of the Phase III CARR, the CSM is ready for shipment to the KSC.

Flight Readiness Reviews

A Flight Readiness Review (FRR) for the CSM, LM, and GSE is conducted at MSC. In general, this review is similar to the review described in the CARR plan. The same systems are reviewed by similar review teams and the SSAD books are continued. However, now there are additional items added due to the inclusion of the ground support equipment and the

SLA. Primary continuity is obtained by use of the SSAD books, their updating during the formal FRR and subsequent special tests.

An FRR Data Review is held at KSC to prepare for the formal FRR Board meeting at MSC. The FRR Board is chaired by the Director of the MSC or his deputy and includes key management personnel from NASA Headquarters, MSC, and KSC. The review objectives are to determine any action required to bring the CSM/LM/GSE to a condition of flight readiness.

The final FRR is conducted by the Office of Manned Space Flight at KSC approximately 5 weeks before the scheduled launch. This FRR is chaired by the NASA Headquarters Apollo Program Director and includes review of all elements of the mission.

Launch Minus 2-Day Review

This review is chaired by the Apollo Mission Director with all the senior manned space flight officials in attendance. This review is held to review all elements of the mission and to assure closeout of all items since the final FRR.

LAUNCH CHECKOUT PROCEDURES

As shown by figure E6-2, technical control of the hardware remains with MSC during the checkout and test operations at KSC. However, the KSC is specifically responsible for conducting the tests and for developing appropriate test procedures to fulfill the test requirements established by MSC.

A Test Requirements Document is prepared and approved by MSC (ref. 5). This document specifically defines the following:

1. Test Constraints - the test sequencing which must be completed prior to accomplishment of particular test requirements and any specific test constraints.

2. Primary Mission Test Requirements Matrix - matrices are listed by system, identifying mandatory test requirements that must be satisfied during the course of spacecraft checkout at KSC. Indication is given of the GSE and facility locations and the desired test guidelines are referenced.

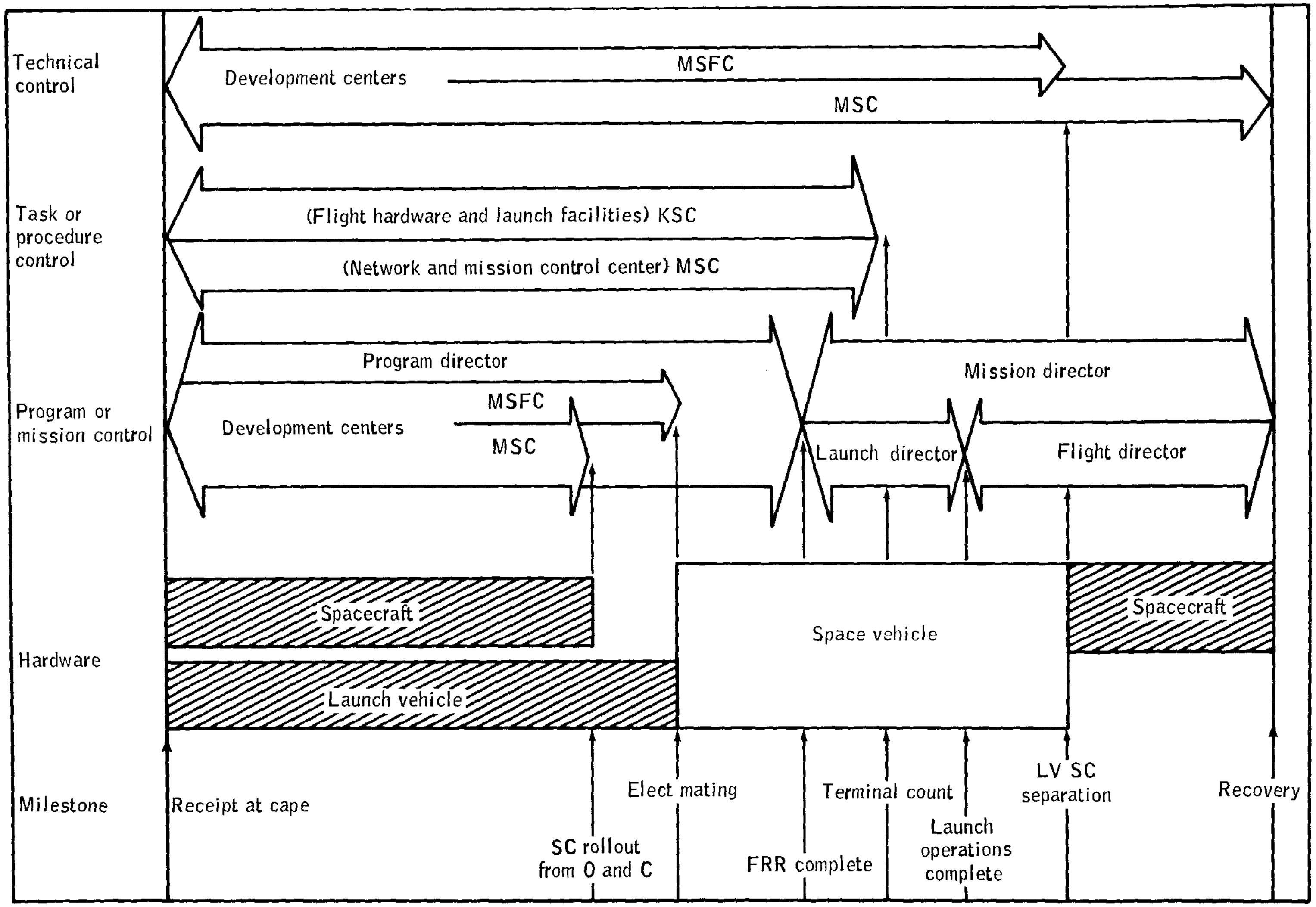

Figure E6-2.- Mission responsibility relationships.

3. Retest Requirements - the general requirements for spacecraft or GSE reverification in the event of test invalidation because of equipment removal, disconnecting, repair, etc.

4. Contingency Test Guidelines - requirements.

5. Safety Requirements.

6. Test Guidelines - these specific sheets reflect the desired test contents, objectives, and test prerequisites.

7. Alternate Mission Test Requirements - matrices are identified for the mandatory test requirements that must be satisfied if a CSM is designated to perform an alternate mission.

Upon receipt of the Test and Checkout Requirements Document from MSC, KSC prepares a Test and Checkout Plan. This plan contains the outline for accomplishing the test requirements defined by MSC at the launch site and additional tests which the KSC considers necessary to verify launch facility, manned space flight network, and launch crew readiness or to satisfy range safety requirements. The Test and Checkout Plan (TCOP) is the master test document and is approved by both KSC and MSC. Changes to this plan and also changes to the facility are reviewed and approved by the KSC and MSC.

Based on the TCOP, detailed Test and Checkout Procedures (TCP) are prepared and approved by KSC. These are the implementing documents which assure that correct detailed information is available prior to the conduct of any test. Changes to these procedures are processed on controlled change request forms which are signed by the appropriate authority. The details for preparation, release, and execution of the TCP are contained in Apollo Preflight Operations Procedures No. 0-202 and 0-221.

Test deviations which may be necessary just prior to the start or during the test are authorized. However, the deviation must be fully documented. Review in this case takes place after the completion of the test, but it is still reviewed and the appropriate levels of authority are provided with the opportunity to modify, change, or to have the tests rerun.

Approximately 2 weeks prior to the scheduled launch date, two separate countdown demonstration tests (CDDT) are conducted. The first of these, called the "wet" CDDT, involves the booster and tanking of all cryogenic systems in all modules. This countdown runs to a simulated lift-off and is then concluded.

A second, or "dry," CDDT is conducted shortly after the "wet" CDDT. This CDDT is primarily concerned with the crew functions. The cryogenic tanks are partially detanked during this CDDT.

The results of the CDDT, "wet" and "dry," are reviewed by the Mission Director and the decision is made to initiate the final countdown. A final review is conducted with all of the senior Manned Space Flight officials at the Launch Minus 2-day Review. At this point the mission is firmly committed.

PART E7

OXYGEN TANK MANAGEMENT REVIEW

GENERAL TANK HISTORY

This part will review the management process described previously as applied to the design, production, test, and checkout of the cryogenic gas storage system oxygen tank.

North American Rockwell (NR) established tentative requirements for a cryogenic gas storage system and issued a request for proposal to interested companies in the spring of 1962. In the summer of 1962, Beech Aircraft Corporation was awarded a letter contract to design, develop, and qualify the Block I Apollo cryogenic gas storage system. This contract was awarded after evaluation of the proposals from Beech and a number of other companies with cryogenic experience. The original contract for Block I was scheduled to be completed by January 1964, and was covered by NAA Specification MC 901-0005 (ref. 6).

A considerable amount of the early effort was expended in development of a spherical heater pressurization system which was both heavy and electrically complicated. In late 1963, a program was established to design an alternate cryogenic fan motor and heater system which was developed and approved for production early in 1964.

The primary vendors for Beech on production hardware were Parker Aircraft for valve modules; Cameron Iron Works for oxygen tank Inconel forgings; Globe Industries, Inc., for the tank motor fans; Simmonds Precision Products, Inc., for instrumentation; Airite Division of Sargent Industries for pressure vessel tank welding; and Metals and Controls Corporation for the tank heater thermal switches.

In 1964, the state-of-the-art for insulation of supercritical oxygen tanks was thoroughly investigated and an improved concept using dexiglass paper and aluminum foil was tested and found satisfactory. Also, the boilerplate BP-14 tanks were completed and shipped to NR in 1964.

Block II competition was held in early 1965, and Beech was awarded this contract in October 1965. Beech made delivery of the first Block I tank in December 1963, and the last one in 1966. There was therefore some overlap of these contracts.

Preliminary Design Reviews were held in May and July of 1965 by NR and Beech. A Program Review was held in December 1965 for the MSC

Apollo Spacecraft Program Manager. Because of the tight delivery schedule, it was decided at the Program Review to assign an NR team to Beech to assist in assuring meeting tank delivery schedules. The configuration control baseline was established by the Critical Design Review held in March 1966 attended by NASA, NR, and Beech representatives. The first Block II oxygen tanks were delivered in July 1966. A First Article Configuration Inspection (FACI) was conducted November 16-18, 1966, with NR, Beech and NASA participating. The FACI confirmed the configuration baseline.

The original specification (ref. 6) from NR to Beech for procurement of the oxygen tank and heater assembly was dated November 1962. No reference is made in this specification to other than design for 28 V dc. Beech issued a specification in 1963 to Metals and Controls Corporation for procurement of the thermal switches for the tank heater assemblies. These thermal switches were to limit the tank temperatures and prevent overheating and were built to interrupt the 28 V dc spacecraft current. The heater GSE was subsequently designed and built by NR with a 65 V dc power supply for use at KSC in initial pressurization of the oxygen tanks. The 65 V dc current was used in order to pressurize the oxygen tank more rapidly than could be done with the 28 V dc spacecraft power supply. NR issued a revised Block II specification (MC-901-0685) to Beech in February 1965 which specified that the oxygen tank heater assembly shall use a 65 V dc GSE power supply for tank pressurization.

Beech issued a specification (14456) in July 1965 to Metals and Controls Incorporated for the thermal switches for the Block II tanks. This revised Beech specification did not call for a change in the thermal switch rating in order to be compatible with the 65 V dc GSE power supply. (The thermal switch, which remains closed in the cold liquid oxygen, will carry the 65 V dc current but will not open without damage with 65 V dc applied.)

NR or Beech never subsequently caught this discrepancy in the GSE and thermal switch incompatibility. The incompatibility had not caused problems previous to Apollo 13 since the thermal switch had never been called upon to open with 65 V dc applied. The extended heater operation using 65 V dc GSE power during the March 27 and 28 detanking at KSC raised the tank temperature to 80° F and called for the thermal switches to open for the first time under these conditions (for which they were not designed or tested). The switch malfunctioned and during the subsequent operation did not provide the tank overheating protection which the KSC test personnel assumed existed.

During the development cycle the following technical problems were encountered.

Tank Vacuum and Heat Leak Problems

Poor vacuum, difficulty in acquiring good vacuum on initial pump-down, and degradation of vacuum from outgassing under vibration were encountered early in the program. These resulted in a high heat leak and caused excessive rates of flow and pressure rise. Early failures to attain satisfactory initial vacuum, including two on qualification tests, were corrected by revisions to test procedures to extend the heat leak stabilization period and upgrade methods of vacuum acquisition.

Vacuum pumping equipment was also modified and improved. A specification change was approved by NR to permit an adequate but more realistic value of heat leak.

Design changes were made in order to correct continued difficulty in securing and retaining good vacuum, and vac-ion pumps were incorporated as an integral part of the tank assembly. Use of the vac-ion pump prevented further gross degradation of vacuum from outgassing. Part of the heat leak was attributed to variation in density of the load bearing insulation in the tank annulus. The insulation was redesigned to reduce the allowable weight and control the overall density of the insulation.

Heat leak did, however, remain slightly over specification on some tanks, and these minor deviations were waived.

Fan Motors

The fan motors for the cryogenic oxygen experienced a number of failures during their production history. A review of these motors was conducted by Globe Industries, Inc., and Beech Aircraft Corporation. The report was issued in January 1967.

The complete manufacturing, handling, and usage of the fan motors at Globe, Beech, and NR was reviewed and the failures that had occurred were grouped in the following nine failure classes:

1. Contamination failures
2. Bridge ring failures
3. Bearing failures
4. Phase-to-phase shorts
5. Grounds

6. Leadwire damage

7. Speed

8. Coastdown

9. Miscellaneous

Other failures, including tolerance build-ups, were reported which could not be classified in the other groups. These are listed under the miscellaneous classification. The corrective actions taken as a result of this review significantly reduced the number of failures. One apparent flight failure in an oxygen tank fan motor occured on Apollo 6. The failure was analyzed as a single-phase short to ground in the heater fan motor circuit. Subsequently, the circuit was revised to include individual fuse protection for each motor and single-phase circuit breakers in each phase.

Vac-ion Pump and Electromagnetic Interference (EMI) Problems

During qualification test there was arcing to the vac-ion pump harness at a mounting screw. Increased clearance was provided. A continuity check was added to verify wiring. Dielectric leakage between the pump and the tank shell also occurred at the vendor plant. A design change was incorporated adding insulation spacers to provide increased clearances, with satisfactory results.

The use of the vac-ion pump led to EMI with other systems on the spacecraft. Corona discharge and arcing of the high voltage lead and connector occurred. This was identified during altitude chamber test of spacecraft 101 at KSC. The fix initiated was to modify the shielding of the high-voltage lead and improve the potting in the connector.

The vac-ion pump is normally not used during flight. It has only been used during vehicle assembly and checkout to assure that the proper vacuum is maintained on the oxygen tank annulus. The circuit breakers for these pumps are opened prior to flight.

Heater Failures

Electrical shorting in the heater circuit occurred twice. A heater element caused a short during acceptance test of a Block I tank at the vendor's plant. A circuit breaker tripped 20 minutes after power was applied. The short was caused by damage to the insulation of the heater lead wires. It was apparently scraped during installation of the wires into the tank or during handling prior to installation. Improved inspection and installation procedures and a pin-to-pin insulation resistance test were initiated. During qualification testing the heater lead wire was burned and a circuit breaker was tripped by overload. The cause was faulty solder joints made during installation. Improved fabrication techniques were put in effect, and applied to all Block II tanks.

During this period of design, development, test, and manufacture, there had been coordination meetings of Beech personnel with the NR and NASA representatives. By the end of 1966, the tanks had completed the major cycle of development and qualification and about 30 tanks had been delivered. In 1967, 17 additional tanks were delivered, three were delivered in 1968, and six were delivered in 1969. These deliveries essentially completed the contract except for eight tanks remaining at Beech. In addition, 11 tanks were used during the early development period for qualification and tests, making 75 tanks in all. Of these 75 tanks, 28 were in Block I and 47 in Block II.

CHRONOLOGY OF APOLLO 13 OXYGEN TANK

The specific tank assembly of interest in this review is oxygen tank no. 2 of CSM 109. This tank is identified as ME 282-0046-008 serial number 10224XTA0008. The other tank on the oxygen shelf of CSM 109 was serial number 10024XTA0009.

The end-item acceptance data package (ref. 7) contains the configuration and historical data relative to this particular tank. Using these data and pertinent spacecraft review data, it is possible to trace this tank through its manufacture, reviews, discrepancies, and tests to launch as a part of an approved flight system.

The Cameron Iron Works made a rough forging of top and bottom tank hemispheres in accordance with Beech specifications and provided the required microstructure analysis of the grain size of the Inconel 718 hemisphere and evidence of satisfactory ultrasonic and radiographic inspection. The forgings were shipped to the Airite Division of Electrada Corporation, El Segundo, California, for machining and welding. After machining, pressure vessel wall thickness measurements were made on the upper and lower hemispheres at about 300 points to establish that girth and membrane measurements were within specified tolerances. The two hemispheres were then welded together, X-rayed for weld inspection, and shipped to Beech Aircraft Corporation on June 15, 1966. Beech Aircraft installed the probe, quantity and temperature sensor, furnished by Simmonds Precision Products, Inc., and cryogenic fan motors furnished by Globe Industries, Inc. Beech also installed the tank insulation and outer Inconel shell.

During the manufacture and testing of the tank 0008 at Beech, a number of discrepancies recorded as Material Review Records were reported and corrected. These discrepancies included:

1. The upper fan motor was noisy and drew excessive current. Corrective action was to remove both fan motors and replace them with new motors serial numbers 7C30 and 7C41.

2. The vac-ion pump assembly insulator was found to have two small cracks along the weld bead. Corrective action was to grind off the pump assembly and insulation weld, to remove and replace the insulator and reweld the assembly.

3. During the minimum flow tests, the oxygen flow rate was found to be 0.81 lb/hr as compared to 0.715 lb/hr specified as maximum in the NR specification. A waiver was requested for this and three other tanks that exhibited similar flow rates. Waiver CSM 0044 was approved by Apollo Project Engineering at NR and by the Acting Manager, Resident Apollo Program Office (RASPO) in accordance with standard procedures. The tank was subjected to the specified end-item acceptance check, including vac-ion functional test, heater pressurization test, electrical insulation resistance tests, dielectric strength tests, proof and purge tests, and minimum oxygen flow tests. These tests were all satisfactorily completed, with the exception of the slightly excessive oxygen flow rate previously discussed, and are documented in the End-Item Acceptance Data Package Book (ref. 7).

Handling Incident

The tank was shipped to NR, inspected, and then installed on an oxygen shelf in June 1968. This shelf was subsequently installed in CSM 106. The vac-ion pump modification, previously discussed, could not be performed with the tank-shelf assembly installed in a service module. For this reason, the oxygen shelf was removed from CSM 106. During the removal sequence the shelf handling fixture broke and the shelf was dropped approximately 2 inches. After the modification and appropriate inspections, the shelf assembly was reassigned to CSM 109.

DR's were written to require inspection and test of the shelf assembly for recertification. These inspections and tests revealed no major discrepancies. It was reported by NR that an engineering analysis was performed to determine the forces which might have been imposed on the tanks due to the "shelf drop." This analysis indicated that the loads were within the design limits of the tanks and that no internal damage should have been sustained. This informal report is not now available from existing files.

To verify that the internal components of the tanks were functional, a series of tests were conducted. The tanks were given a repeat of the acceptance and verification tests which are normally conducted by NR prior to installation of an oxygen shelf in a service module. All of these tests were passed successfully, with no significant changes from the previous test results. NR does not fill the tanks with liquid oxygen during their test, assembly, and checkout activities at the plant.

At the completion of the required vac-ion pump modifications and with the successful test results obtained, the shelf assembly condition was reviewed by NR engineering, R&QA, and the RASPO and installed in CSM 109. All appropriate signatures were obtained on the DR's, copies of these were provided to the Subsystem Manager at MSC, and copies were also included in the Subsystem Summary Acceptance Document (SSAD) book for spacecraft 109.

At the Phase I CARR for CSM 109, November 18-19, 1968, the incident was again discussed by the CARR subsystem team with NR engineering and NASA/RASPO. Documents and NR test results were reviewed and the shelf was accepted. It had passed all required tests, the analysis indicated that estimated loads had not exceeded design limits, and the entire record had been properly reviewed. The incident had been explained in accordance with all of the management control systems in effect.

The Phase III CARR on May 26-28, 1969, verified that the shelf was installed in CSM 109 and that test data verified satisfactory oxygen shelf performance in accordance with the test DR written by NR and NASA/RASPO.

The information concerning the handling incident was included in the SSAD books for spacecraft 109. It was not reviewed by the Flight Readiness Review (FRR) Board. Equipment which has successfully passed all tests and has been certified as flightworthy does not require additional reviews unless additional problems are discovered. As no problems were encountered, the CSM 109 FRR on January 15-16, 1970, considered the oxygen shelf checkout as having been satisfactorily performed and recommended the system as flight ready.

Because the handling incident had occurred early in the review cycle for spacecraft 109 and had been closed out, it was not reconsidered in any detail during the decision process regarding the detanking incident. NR personnel at Downey were aware of the handling incident. However, Beech, KSC, and senior MSC Management were unaware of the incident.

The R&QA reporting and data retrieval system is designed to enable records to be readily obtained. However, this is not an automatic action. It is necessary for the concerned people to initiate the action; that is, request the record search. By virtue of the general concept that is applied to Apollo, this search of the records is seldom done. Flight equipment is either flightworthy or not. There is no gray area allowed between good and bad equipment.

Detanking Incident

After shipment to KSC, build-up checkout activities proceeded normally until the countdown demonstration test (CDDT) sequence wherein the tanks were pressurized, checked, serviced with liquid oxygen, and then detanked. Detanking difficulty developed during sequence 29-009 of Test and Checkout Procedures (TCP), TCP-K-0007V2, at 10:55 p.m. on March 23, 1970, when oxygen tank no. 2 did not decrease to about 50 percent quantity as expected.

The problem was first attributed to a faulty filter in the associated ground support equipment (GSE) and an Interim Deficiency Report (IDR 023) was initiated for evaluation of the filter.

Troubleshooting of test sequence 29 was continued by the NR Systems Engineers, the NASA (KSC) Systems Engineers, and the NR Systems Specialist with the actions monitored by a KSC reliability specialist and a KSC safety specialist in accordance with specified KSC procedures.

A decision was made on March 23, 1970, at 11:37 p.m. that TCP-K-0007V2 test procedures could be continued. This decision was made by the NR Systems Engineer, NASA (KSC) Systems Engineer, and the NR Systems Specialist.

TCP-K-0007V2 was continued through sequence 29-014 by 2:55 a.m. on March 24, and the IDR 023 was upgraded to a GSE/Discrepancy Report (DR) for filter evaluation on March 24, 1970.

The TCP-K-0007V2 test sequence 29 was reinitiated on March 27, 1970, at which time it was known that the suspect GSE filter was not malfunctioning. An Interim Discrepancy Report (IDR 040) was written to investigate detanking and change detanking procedures to assist in detanking. After substantial time was spent in the detanking attempt, the IDR 040 was changed to a spacecraft DR 0512.

A conference including MSC subsystems engineers and KSC Apollo CSM Manager was held and a Beech engineer was contacted by telephone to discuss the problem. It was decided that the difficulty was caused by allowable looseness in a fill line fitting and it was decided to try detanking using fans and heater on oxygen tank no. 2. This was started on March 27, 1970, during the second shift.

DR 0512 was signed by the NR Systems Engineer, the NASA Systems Engineer, and the NR Systems Specialist (all of whom are assigned to KSC), and varied the procedures of the basic TCP. This variation did not result in satisfactory detanking.

DR 0512 was further amplified on March 28, 1970, at about 4 a.m., to provide for a pressure pulsing technique whereby the tank vent was closed and the tank was pressurized to 300 to 340 psig, allowed to stabilize for 5 minutes, and then vented through the fill line. This procedure was concurred in at the time by NR Systems Engineer, NASA Systems Engineer, NR Systems Specialist, and NR Systems Manager, all of whom are assigned to KSC. This procedure was followed for five pressure cycles and the tank was emptied.

The decision to be made by KSC in consultation with NR and MSC was whether to leave the oxygen shelf in the spacecraft or to exchange it for a different one. This was a critical decision because changing a major unit such as the oxygen shelf at the KSC is not a normal practice. It can be accomplished, but it must be done manually at some risk of damage to adjacent components. At the NR factory, there is a specifically designed item of GSE with which to remove the shelf.

Many telephone calls were made concerning the detank problem, and several of them were conference hookups so that most of the participants could hear the entire conversation. The KSC Director of Launch Operations and the MSC Apollo Spacecraft Program Manager led the ensuing investigation which included key technical experts at Beech, similar experts at NR, and the subsystems managers at MSC.

During the weekend beginning March 27, MSC developed a comprehensive checklist of questions which had to be answered prior to making a decision concerning the oxygen tank:

1. Details and procedures for normal detanking at Beech and KSC.

2. Details of abnormal detanking at KSC on March 27 and 28.

3. Hazards resulting from a possible loose fill tube in the oxygen tank.

4. Can the tank be X-rayed at KSC?

5. Could loose tolerances on the fill tube cause the detanking problem?

6. Should a blowdown and fill test be made on the tank?

7. Disassemble both oxygen tanks from Service Module 2TV-1 and examine components.

All of the checklist questions were answered by test, analysis, and inspection. The report of the Beech investigation, contained in reference 8, included the following conclusions:

1. "Based on manufacturing records, the Teflon tube fill line assembly was installed.

2. Total gap areas in the assembly after cooldown could vary from 0.004 in^2 to 0.09 in^2 from tank to tank.

3. Based on allowable tolerances, gap areas on tanks could approach the area of 3/8 inch fill line, thus accounting for the inability to detank per methods used at KSC.

4. Normal stresses on the Teflon plug are not sufficient to cause cracking or breakout of the plug.

5. The assembly, fabricated to print dimensions, cannot come apart in the installation.

6. Tank X-rays are not clear enough to show the fill assembly.

7. The delta pressure across the coil assembly and disconnect is very small.

8. Energy level developed by shorting capacitance plates on probe is too low to cause a problem."

In addition to these conclusions, Beech also provided NR a copy of their detanking test procedures and the calculations used to reach their conclusions.

Based upon the Beech information, the condition of the 2TV-1 oxygen tank fill line determined by direct inspection and the understanding that the detank procedures at the KSC and at Beech were different, it was concluded that the tank was flightworthy. The primary participants in reaching this conclusion were the NR CSM Program Manager, the KSC Director of Launch Operations, and the MSC ASPO Manager. The fact that these people did not have complete or correct information to use during the decision process was not determined until after the accident.

The information which subsequent review determined to be incomplete or incorrect included the following:

1. Neither the KSC Launch Operations Director nor the MSC ASPO Manager knew about the tank handling incident which had occurred at NR-Downey.

2. The last portion of the detanking procedure at Beech is similar to that used by KSC. No one appeared to be aware of this similarity between the procedures. At one time during the early portions of the program they were, in fact, different.

3. All of the key personnel thought that the oxygen tank on Service Module 2TV-1 had experienced detanking problems similar to those experienced at KSC. As this tank was available, it was disassembled and inspected. The examination of the internal tank parts showed a loose-fitting metal fill tube and it was concluded that this loose fit was the cause of the detanking problem. Subsequent review has revealed that the 2TV-1 tank probably detanked in a normal manner.

4. The senior managers were not aware that the tank heaters had been left on for a period of 8 hours. It appears this information was provided to NR-Downey by telephone during a long conversation. However, it was not considered during the decision process. No one at MSC, KSC, or NR knew that the tank heater thermostatic switches would not protect the tank from overheating.

The management system alerted the right people and involved them in providing technical information to the responsible program managers. Communications were open, unrestricted, and appear to have been nearly continuous. All of the modified KSC detank procedures were correctly documented and other reports were correctly filled out. The problem was that inaccurate and misleading information was provided to the managers.

Any consideration of whether management decisions would have been different if the correct data had been provided is highly speculative. However, it is likely that requests for additional tests or data may have been considered during the discussion if the correct information had been available.

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PART E8

OXYGEN TANK MATERIAL SELECTION

The original design of the cryogenic oxygen storage system was based on state-of-the-art existing in 1962 and subsequent developments during the course of the contract test and evaluation phase. The tank contractor, Beech Aircraft, Boulder, Colorado, started the design using materials considered compatible based on existing cryogenic knowledge. A limited program was followed in qualifying components, such as the Globe fan motors in the company's test facilities.

The first formal application of Nonmetallic Materials Selection Guidelines was imposed on NAA by CCA 1361 dated April 17, 1967. This Change Authorization required that the contractor implement ASPO-RQTD-D67-5A dated April 17, 1967, and recommend a detailed plan for analysis, application testing, selection, and approval of nonmetallic materials to assure that all potentially combustible applications are identified and controlled. In addition, the contractor was required to recommend any design and/or material changes necessary to meet these criteria. This change was effective on Spacecraft 2TV-1, 101, and subsequent.

The cryogenic oxygen gas storage system was categorized as Category D--Material Applications in High Pressure Oxygen System--for material selection and control purposes.

Requirements for Category D are as follows: This category shall include those materials used in greater than 20 psia oxygen systems. Materials shall have prior use history in oxygen service, with no fire or explosion experience.

FUNCTIONAL DESCRIPTION

Materials for such applications as filters, seals, valve seats, and pressure bladders shall be covered by these criteria.

Material Property Requirements

Propagation rate.- No test required.

Thermogravimetric analysis and spark ignition test, reference 9.- This test is designed to determine the weight loss and outgassed vapor spark ignition characteristic of materials under test. A material evolving significant vapors verified by weight loss and having a visible flash at a temperature less than 400° F is unacceptable. A material that shows evidence of charring or sustaining combustion at a temperature less than 450° F is unacceptable. A material that shows evidence of charring or sustaining combustion at a temperature less than 450° F is unacceptable for use in crew bay areas.

Odor, carbon monoxide, and organics, reference 9.- Materials shall be tested for carbon monoxide and total organics. If the material yields over 25 micrograms of carbon monoxide per gram of material or over 100 micrograms of total organics per gram, it will be rejected. If it passes this test, it will be evaluated for objectionable odor by a test panel of 5 to 10 members. If the odor is objectionable, the material will be unacceptable.

Friction and impact ignition, reference 9.- This test is to determine the sensitivity and compatiability of nonmetallic materials with pure oxygen for use in the high-pressure oxygen system. Only materials that have passed other required tests will be subject to this test. The material will be subjected to three successive tests at 1.5 kilogram meters impact testing at successively higher gaseous oxygen pressures until a reaction is observed by discoloration, evidence of combustion, or.detonation. To be acceptable, the material must not show a reaction at the maximum use pressure plus 2000 psi.

Friction and impact ignition.- Materials shall not ignite when tested to the requirements of Appendix D of reference 10.

The presently applicable contractual specification (ref. 9) was published and placed on contract by CCA 2147 to record the criteria and requirements actually in force for the Apollo contract. Modifications to the basic document are made as the knowledge increases, and it was last revised in November 1969.

The contractor is primarily responsible for the selection of materials in contractor furnished equipment (CFE) as prescribed by contract. NASA publishes materials selection requirements and reviews materials selected by the contractor. A Material Selection Review Board is established at the contractor's facility to review material selection and to approve or reject all deviation requests. The contractor board submits all decisions to the Material Review Selection Board at MSC for review and approval. The prime board, MSC, indicates concurrence or nonconcurrence to the contractor board within 5 days of receipt of the lower board's decisions.

Present requirements for material selection are essentially the same as those previously cited and are listed in detail in reference 10.

Materials Listing

A listing of materials was prepared by Beech and furnished to NR. The listing was checked at NR for completeness and compatibility and entered into the Characteristics of Materials (COMAT) list and forwarded to MSC in October 1969. This COMAT package was transmitted to the MSC/GE Materials Engineering Support Unit where it was reviewed and signed off as complete and accurate by the Materials Engineering Unit Manager. All materials are shown to be compatible for the use contemplated except Drilube 822 which is an assembly lubricant used in very small quantities. The MSC COMAT shows this material classed as requiring the submission of a Material Usage Agreement (MUA) for approval.

The Drilube was judged acceptable for the use contemplated in accordance with the blanket waiver given for outgassing of materials tested at MSC on the 2TV-1 and CSM 101 vehicles.

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PART E9

SAFETY AND RELIABILITY AND QUALITY ASSURANCE (R&QA)

INTRODUCTION AND ORGANIZATION

General

The Apollo Program has a firmly established safety requirement in the basic program objective. The original objective of the program was to land men on the Moon and return them safely to the Earth. The program management, design, review, and monitoring procedures described in previous sections of this Appendix are designed to assure that all program problems, including safety, are presented to the appropriate management decision makers at selected program maturity points.

The safety system and organization is designed to provide an independent specialized monitoring and evaluation function for the program line management. The following figures and descriptions of responsibilities outline the safety organization of NASA as it applies to the Apollo Program, and the contractor-subcontractor organization as it applies to the Apollo Program generally, and the cryogenic gas storage system specifically.

NASA Headquarters

The Aerospace Safety Advisory Panel is established to provide a direct, nonorganizational overview on safety for all programs for the Administrator (fig. E9-1). The charter for this panel specifies access to any program information necessary for their safety audit function and full support of their requirements by the NASA Safety Officer and other elements of the organization.

The NASA Director of Safety is responsible for exercising functional management authority and responsibility over all NASA safety activities. This includes development of policy, procedures to implement policies, and review and evaluation of conformance to established policy. He is also charged with supporting Program Directors and Instutional Directors in discharging their safety responsibilities. His review and concurrence are required for the safety portion of each Project Plan and Project Approval Document.

The NASA Director of Safety reports to the Associate Administrator for Organization and Management.

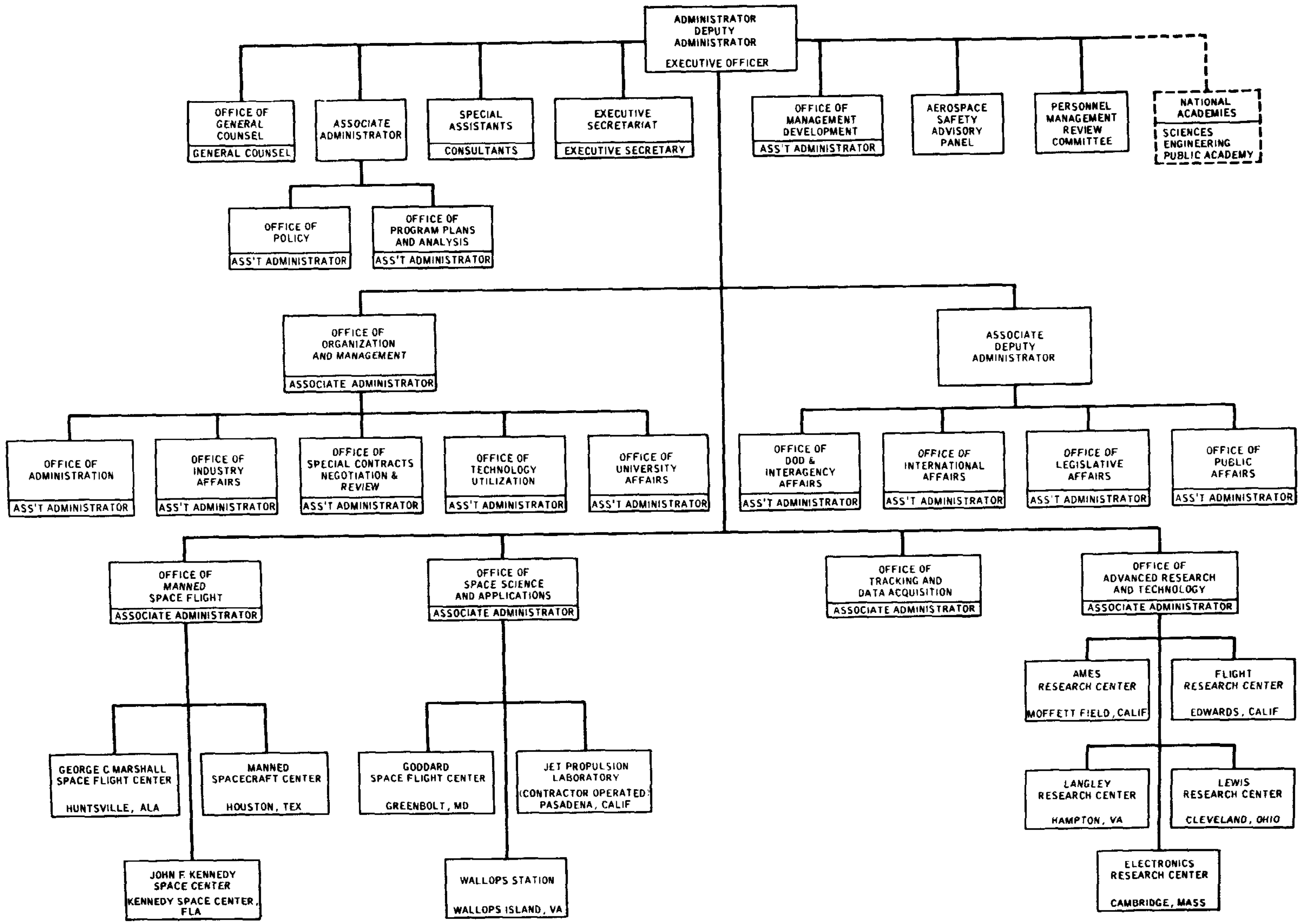

Figure E9-1.- National Aeronautics and Space Administration.

The office of the Associate Administrator for Manned Space Flight (MSF) (fig. E4-3) has several offices with either a primary or secondary responsibility for safety.

The Director, Manned Space Flight Safety Office, has a dual organizational responsibility to the Associate Administrator for Manned Space Flight (AA/MSF) for program guidance and policy direction. He also serves in the office of the NASA Safety Director as Assistant Safety Director for Manned Space Flight Programs, assisting in the development of overall NASA-wide safety policy, guidance, and professional safety standards. In this NASA Assistant Safety Director assignment, he is under the cognizance of the Office of Organization and Management. In accomplishing his responsibility as Manned Space Flight Safety Director, he advises the MSF Program Directors and the AA/MSF on all matters involving manned flight safety and develops and documents appropriate safety policy for these programs. He audits the program offices and MSF Field Centers to insure compliance with established policy and develops accident investigation and reporting plans for use in the event of flight anomalies. He also develops the Manned Space Flight Awareness Program.

Bellcom, Inc., is under contract to AA/MSF to perform studies, technical fact finding and evaluation, analytical investigations, and related professional activities in support of Manned Space Flight Programs. In support of the Apollo Program, this contract capability is available under the direction of the Director, Apollo Program, for safety studies or analyses as required in support of his responsibilities to systematically identify hazards and risks and take all practical measures to reduce risks to acceptable levels.

Manned Space Flight Mission Directors are assigned as Deputy Program Directors for specific missions and are responsible for insuring thorough inter-Center/OMSF coordination for that mission. The Mission Director insures that consideration is given to all problems and proposed changes affecting safety and to advise the Program Director of any disagreement with proposed actions from the standpoint of assuring quality hardware and flight safety.

The Director, Mission Operations, is responsible for directing and evaluating the development of the total operational capability necessary for the conduct and support of Manned Space Flight missions. These responsibilities are performed in support of the Manned Space Flight Program Directors under the cognizance of the Associate Administrator for Manned Space Flight. In accomplishing this operational responsibility, the Mission Operations Director works with the MSF Director of Flight Safety to insure development of operation safety plans.

The Director of Reliability and Quality Assurance is responsible to the Assistant Administrator for Industry Affairs to formulate and develop reliability and quality assurance policies and to prescribe guidance and procedures to implement approved policies. He is also responsible for assessing the effectiveness of these programs throughout the Agency and for keeping the management informed of the status of the program. He participates in investigations of major accidents and mission failures whenever reliability and quality assurance could have been a contributing factor. He also initiates and conducts special studies of problems affecting the reliability and quality of NASA hardware.

The Director, Manned Spacecraft Center, under the supervision of the AA/MSF, manages the development activities of the Apollo Program, with emphasis on providing spacecraft, trained crews, and space flight techniques. In carrying out these functions, he procures spacecraft systems and monitors and directs contractor activities. He also selects and trains flightcrews, establishes mission and test requirements, and plans and executes missions under the direction of the Mission Operations Director.

The Director, John F. Kennedy Space Center (KSC), under the supervision of the AA/MSF, develops, operates, and manages the Merritt Island Launch Area (MILA) and assigned programs at the Eastern Test Range (ETR) and insures that KSC operations meet the requirements of NASA Safety Standards.

Manned Spacecraft Center

The Safety Office is the focal point for the development, implementation, and maintenance of a safety program at MSC. The office implements requirements established by NASA Headquarters, maintains a current MSC Safety Plan and Manual, and participates as an advisor to the Director, MSC, in major spacecraft reviews. The office assesses the effectiveness of contractors in their safety functions and assists MSC directorates, program offices, and contractors in safety matters.

The Safety Office is functionally divided into a number of subdivisions to accomplish their assigned duties, as shown in figure E9-2.

The Manned Flight Awareness Office is responsible for developing a motivational program to instill in each individual associated with manned space flight a personal awareness of their responsibility for the lives of the astronauts and mission success of space flight missions. This responsibility is largely accomplished by development and publication of motivational literature and by scheduling and coordinating astronaut and management official visits to contractor and subcontractor plants in support of the Manned Flight Awareness Program.

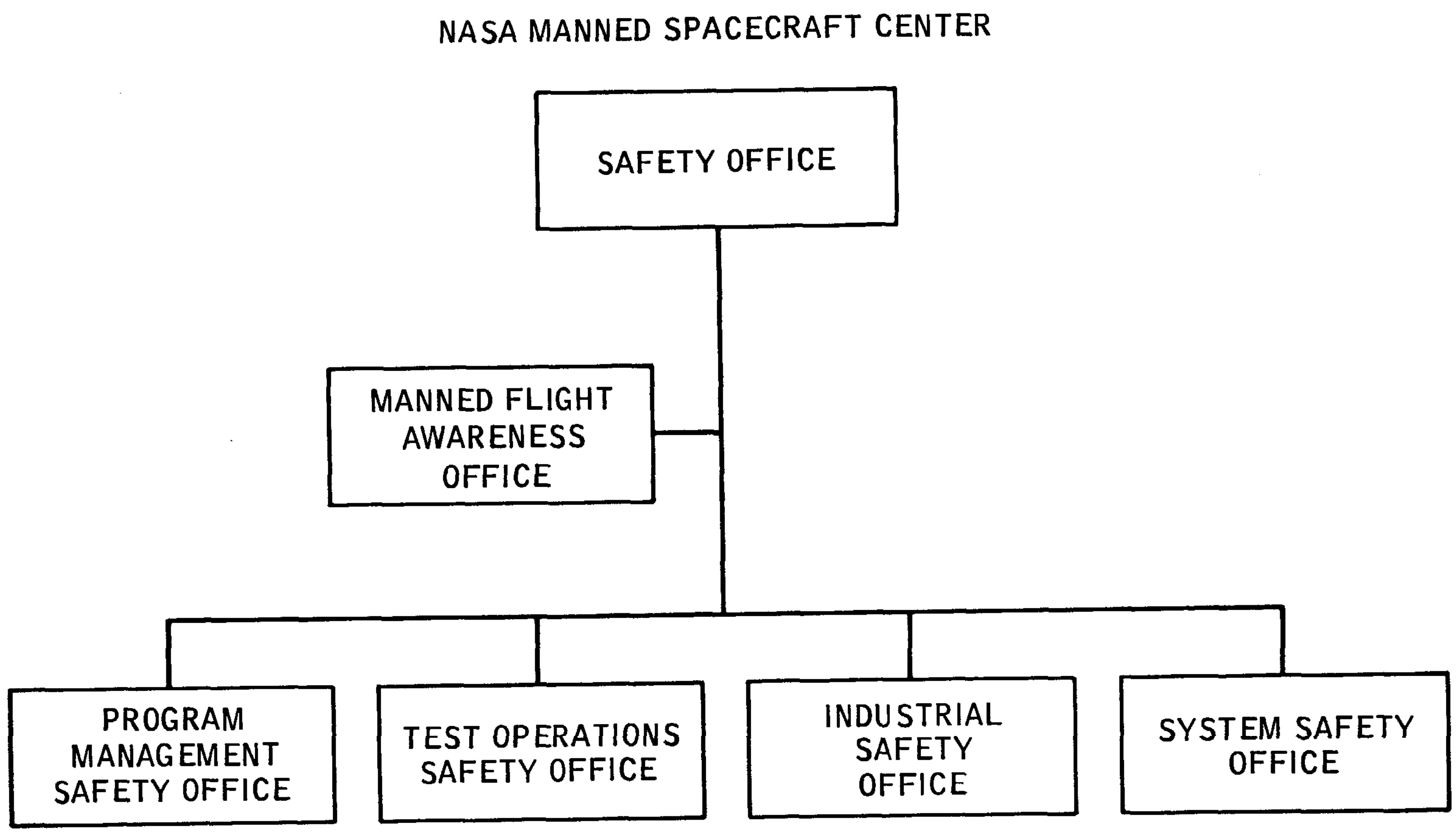

Figure E9-2.- MSC Safety Office organization.

The Program Management Safety Office develops and applies a system safety program for flight hardware contracts. System safety guidelines are identified to MSC program offices and directorates and through them to contractors. The Program Management Safety Office represents the Manager, Safety Office, on program major milestone reviews and evaluates contractor and MSC system safety requirements for particular programs. This office also provides for identification and tracking of hazards throughout the life of a system. In accomplishing this responsibility, the office assesses mission rules, flight plans, and crew procedures to identify potential hazards and assure that they are eliminated or controlled. They also evaluate design and procedure changes for safety implications and monitor space flight missions in real time to appraise the Manager, Safety Office, of safety-related amonalies. They maintain close interface with MSC program elements to provide inputs for trade-offs involving safety and performance.

The Test Operations Safety Office is the subdivision of the Safety Office that establishes a safety program to insure the safe conduct of hazardous tests involving human subjects, tests of GFE astronaut equipment, and special tests of spacecraft. The office evaluates test facilities and operations to determine hazardous activities and provides test officers for activities considered to be of an extremely hazardous nature. They compile and evaluate reports and findings of Operational Readiness Inspections (ORI's) and distribute these reports as required.

The System Safety Office develops, implements, and maintains a system safety program for manned spacecraft efforts involving preliminary analysis, definition, and design phases. The office also provides system safety support for other elements of the Safety Office. Specifically, this office assists in the preparation of system safety plans from the initial purchase order or request for proposal through the procurement stage and then audits the system safety activities of the contractor or MSC organizational element throughout the program.

The Industrial Safety Office directs and coordinates comprehensive industrial, public, and traffic safety programs, including a fire prevention and protection program and an ordnance safety program covering MSC operations and activities including test facilities; develops and coordinates the MSC/contractor industrial safety program; and evaluates the effectiveness of all MSC-directed industrial safety activities.

The Reliability and Quality Assurance Office at MSC (fig. E9-3) is a fundamental element in the safety system. The office is co-located with the Safety Office and the same man heads both offices. The R&QA office develops and implements the reliability and quality assurance programs for the Center to assure that spacecraft, spacecraft systems, and supporting systems are designed and built to perform satisfactorily in the environment for which they are designed. This office also reviews

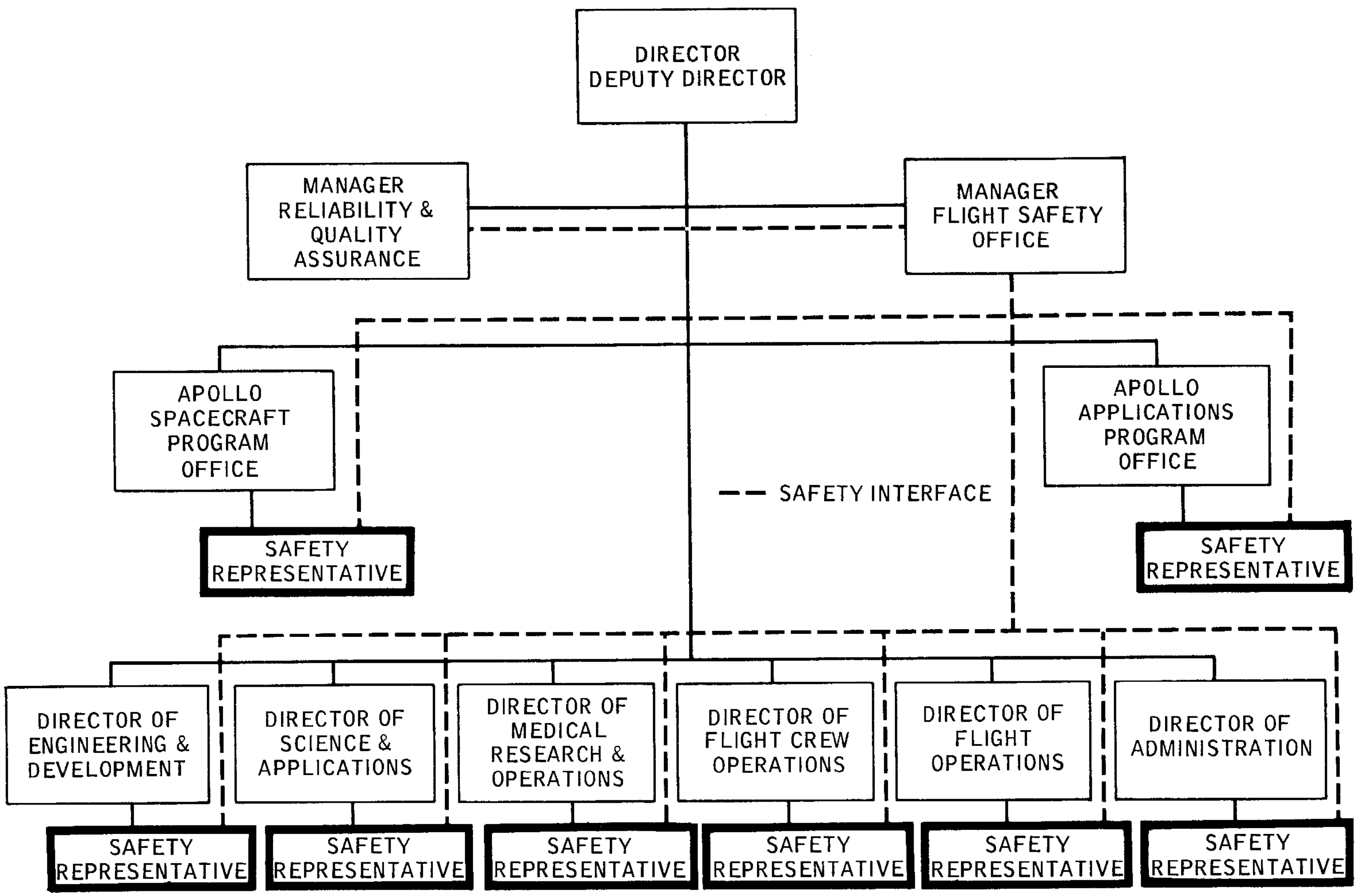

Figure E9-3.- Safety Functional Office, NASA Manned Spacecraft Center.

and evaluates R&QA information and activities of contractors and provides onsite monitoring. The office also provides specialized studies for safety reviews and provides direct support to program managers for design reviews, configuration management change control, flight readiness reviews, and real-time mission support.

The MSC Safety Plan establishes the organized MSC system safety program. The plan applies to Center activities and contractors under NASA/MSC direction. The plan is oriented toward spacecraft systems and crew safety and does not cover all elements of a total safety program.

The general intention of the safety program is to establish the primary responsibility for safety of spacecraft and GSE hardware and software with the program office/contractor. The responsible directorates are recognized as having the primary responsibility for the safety of mission operation and crew procedures. The MSC Safety Office has the primary responsibility for assessing manned safety of spacecraft flight and ground testing and acting to insure system safety consideration by all MSC and program contractor elements.

The MSC offices and directorates with prime system safety responsibilities are shown in figure E9-3 with their functional relationships with the Safety Office indicated by the dashed lines. Each of these offices and directorates has established a single point of contact for all safety matters. This contact interfaces directly with the Safety Office and has unimpeded access to top management of his directorate or office on safety matters. The spacecraft hardware and operations safety responsibilities of each of these offices are as follows:

1. Program offices manage the design, test, and manufacture of spacecraft systems and related GSE to assure proper contractual safety requirements. They implement Safety Office policies and procedures and resolve incompatibilities between mission requirements, mission profiles, operational constraints, and spacecraft capabilities. They also provide the basis for certifying design maturity and manned flight safety.

2. Flight Operations Directorate is responsible for:

(a) Trajectory and flight dynamics analysis.

(b) Mission control requirements.

(c) Mission rules and spacecraft systems handbooks.

(d) Ground instrumentation requirements.

(e) Emergency real-time procedures.

(f) Landing and recovery testing and operations. Coordinating recovery operations with DOD.

(g) Coordinating safety matters with Air Force Eastern Test Range.

(h) Providing the basis for certifying design maturity and manned flight safety.

3. Flight Crew Operations Directorate:

(a) Assures the adequacy of flightcrew selection and training.

(b) Establishes crew procedures and spacecraft operational constraints.

(c) Conducts mission planning.

(d) Establishes crew station design requirements.

(e) Conducts simulations (nominal operations and abort).

(f) Develops operations handbooks and general flight procedures.

(g) Approves all KSC test and checkout operating procedures involving flightcrews.

(h) Conducts and supports tests with aircraft where they are used to develop and evaluate operational capabilities of space-related hardware and operations.

(i) Provides the basis for certifying design maturity and manned flight safety.

4. The Engineering and Development Directorate:

(a) Assures the adequacy of design, manufacture, and test of equipment and the cognizance of this Directorate.

(b) Assures that safety is properly integrated and that system safety requirements are provided in contractual requirements.

(c) Provides technical support to MSC programs through subsystem management programs.

5. The Science and Applications Directorate:

(a) Performs flight experiments and special experimental tasks.

(b) Assures proper integration of system safety policies and requirements into design and operation of all space science experiments.

(c) Coordinates with Safety Office on safety requirements for special experiments.

(d) Assures that safety requirements are properly implemented in the design and operation of the Lunar Receiving Laboratory.

(e) Provides the basis for certifying design maturity and manned flight safety.

6. The Reliability and Quality Assurance Office:

(a) Supplies failure mode and effect analysis of spacecraft systems, subsystems, GFE, and experiments.

(b) Provides failure trends.

(c) Determines safety categories.

(d) Coordinates with Government inspection agencies to insure that safety-critical items satisfy established requirements.

(e) Approves failure closeout statements.

7. The Medical Research and Operations Directorate:

(a) Provides world-wide medical support for manned missions and provides flight surgeons during missions.

(b) Provides medical coverage for all tests involving human subjects.

(c) Monitors the physical condition of human participants with the authority to stop testing if continuation might result in injury or death to the test subject.

(d) Ascertains by physical examinations the satisfactory physical condition of the test personnel or flightcrews and certify their satisfactory physiological condition.

(e) Participates in test planning and approves all physiological test standard procedures involving human participants.