APPENDIX E

REPORT OF PROJECT MANAGEMENT PANEL

CONTENTS

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PART E1

TASK ASSIGNMENT

The Project Management Panel was established by the Apollo 13 Review Board to review those management systems in the Apollo Program which were pertinent to the Apollo 13 accident. In effect, this task required the review of all appropriate design, manufacturing, and test procedures covering vehicle systems which may have failed in flight, including the means by which various organizations coordinated their individual efforts in the total process. The Panel took special care to evaluate carefully the safety management system which was applicable to Apollo 13.

Principal questions addressed by the Management Panel focused on the organization, procedures, and systems used to monitor and control CSM design, manufacturing, test, assembly, and final certifications of flight equipment, and particularly of the cryogenic oxygen system used in the service module electric power system and environmental control system.

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PART E2

PANEL MEMBERSHIP

Panel 4 was chaired by Mr. E. C. Kilgore, Deputy Chief, Engineering and Technical Services, Langley Research Center. The Board Monitor was Mr. Milton Klein, Manager, AEC-NASA Space Nuclear Propulsion Office. Panel members were:

Mr. R. D. Ginter, Director, Special Program Office
Office of Advanced Research and Technology (OART)
NASA, Headquarters, Washington, D.C.

Mr. Merrill Mead, Chief, Programs and Resources Office
Ames Research Center
Moffett Field, California

Mr. James B. Whitten, Asst. Chief, Aeronautical and Space Mechanics Division
Langley Research Center
Hampton, Virginia

In addition, Mr. R. C. Puffer of MSC Security assisted the Panel by preparing the section of the report on Security.

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PART E3

SUMMARY

INTRODUCTION

The Management Panel carried out a detailed in-depth review of the Apollo Spacecraft Program Office organizational structure and the management system used to control both command and service module (CSM) hardware development and decision-making processes. The review examined the system for Apollo and focused attention on the specific cryogenic oxygen tank directly involved in the Apollo 13 accident. Key management personnel at the Manned Spacecraft Center (MSC), the Kennedy Space Center (KSC), and Apollo contractors and subcontractors were interviewed. These interviews were specifically aimed at understanding what decisions were made regarding the oxygen tank system for Apollo 13, who participated in these decisions, what information was available from the management system, how effectively the organizational elements functioned in reviewing, communicating, and carrying out assigned responsibilities, and whether management system changes are required in view of the oxygen tank accident. Records of the oxygen tank reviews, discrepancy reports, failure reports, and procedures were examined to determine if the review systems and configuration control system functioned as they were intended. Separate reviews were made of the Security, Safety, and Reliability and Quality Assurance (R&QA) management systems to determine effectiveness.

Visits were made to the CSM prime contractor, North American Rockwell (NR), Downey, California, and to the oxygen tank subcontractor, Beech Aircraft, Boulder, Colorado, during which discussions were held with key design, test, and manufacturing personnel. Reliability inspection, safety, configuration-control and process-control procedures and systems were reviewed and examined in detail. KSC operations were reviewed and discussions were held with key test and launch operations personnel regarding their responsibilities, procedures, and controls. Similar discussions were held with MSC Apollo CSM key management and engineering personnel. Throughout its analysis, the Panel devoted particular attention to the history of the Apollo 13 cryogenic oxygen tank no. 2 including design and manufacturing waivers, discrepancies, and anomalies and how these were handled by the Apollo management team.

General Technical Capability

The Panel found key Apollo personnel to be technically capable and dedicated to producing a reliable and safe spacecraft system. Although there have been cutbacks in the total number of Apollo personnel, the morale of the remaining Apollo team is considered by officials interviewed to be high. Reductions in personnel complements as the flight rate has been reduced have not detrimentally impacted the experience level within the Program to this point. Moreover, critical flight and ground system personnel requirements have been carefully reviewed by project officials to insure adequate manning. During the Apollo Program, there have been changes in key management personnel. The Panel found that attention was given to maintaining continuity of experience by essentially promoting from within the Apollo Program. Some technicians with considerable CSM experience have been replaced at NR-Downey by technicians from other programs with more seniority, but no CSM experience. This was recognized as a potential problem and an intensified training program was instituted. Continued surveillance of the contractor technician experience level and capability is necessary.

Division of Responsibilities

The Apollo spacecraft organization involves a large number of contractor, subcontractor, and Government organizations. It was found that these organizations understand their individual responsibilities and that necessary coordination processes were in effect. This process provides a system of checks and cross-checks to assure that detailed consideration and attention is given to problems by the right organizations prior to final flight commitment.

Cryogenic Oxygen Tank Design

Apollo oxygen tank no. 2 was designed in the 1962-1963 time period by Beech prior to the formation of the formal design review and subsystem manager systems which now exist at MSC. During the design phase, there was limited participation by MSC technical personnel in the early design. The primary emphasis at this time by both the prime contractor and MSC was on the thermodynamic performance of the oxygen system. The tank did receive informal design reviews primarily by NR and Beech personnel. Even though these reviews were made, it was found that the final design resulted in a complex assembly procedure with a wiring cluster which cannot be inspected after assembly in the tank. However, the complexity of the assembly and the inability to inspect the tank interior components after assembly was recognized by Government, NR, and Beech personnel. Consequently, a detailed step-by-step manufacturing and assembly procedure was established and carried out with checklist-type Beech inspections, supplemented by NR and Government inspections at defined critical points. A First Article Configuration Inspection (FACI) was held on the oxygen tank in 1966 which was jointly signed off by MSC and contractor subsystem managers. No subsequent formal design reviews were held.

A thermostatic switch (thermal switch) was incorporated into the Block I oxygen tank heaters to avoid overheating while using 28 V dc spacecraft power. After receipt of the Block II oxygen tank specifications from NR in February 1965, which required the tank heater to operate not only on 28 V dc spacecraft power but also with 65 V dc GSE for rapid tank pressurization during launch operations at KSC, Beech did not require their Block I thermal switch supplier to make a change in switch rating. NR never subsequently reviewed the heater assembly to assure compatibility between the GSE and the thermal switch. This resulted in NR, MSC, and KSC personnel subsequently assuming that the tank was protected from overheating while using the 65 V dc power supply.

Configuration Control Procedures

The Panel found that a strict and rigorous management system exists on the CSM for configuration control, problem reporting, customer acceptance readiness reviews, and flight readiness reviews. Both contractors and Government CSM organizations participate in this system. R&QA organizations independently monitor, record, and report all problems and approved resolutions. Examination of documentation, such as failure reports, discrepancy reports, and waivers generated in the management system and applicable to the Apollo 13 oxygen tank, demonstrated to the Panel that the management system was being followed closely. Closeouts were being accomplished with authorized approvals.

Oxygen Tank Handling Incident at Downey

In the case of the Apollo 13 oxygen tank handling incident at NR-Downey, the Panel found that a Discrepancy Report was written and functional tests were made by NR Engineering. The incident was judged to have caused no tank damage by the contractor's systems engineers and representatives of the RASPO at Downey. Also, the oxygen tank subsystems manager at MSC was made aware of the incident. Subsequent functional tests were successfully passed. The Discrepancy Report was closed out in the authorized manner. Although the handling incident was not reported to the Apollo Spacecraft Program Manager, it should be noted that such reporting of Discrepancy Report closeouts is not required in all cases. Once this incident was closed out in the manner prescribed by the Apollo management control system, it was not reopened as a possible factor relating to the later detanking problem at KSC.

KSC Detanking Problems

In the case of the detanking problem at KSC, it was found that all authorized Discrepancy Reports were filed and signed off. The change from normal detanking procedures was made to use the tank heaters and fans in an attempt to boil off the liquid oxygen in the tank. This was unsuccessful and the normal procedure was further altered by use of a pressure pulsing method. These changes to the test procedures were made by the KSC Systems Engineer and NR Systems Engineer who were on station. They obtained concurrence of the NR lead systems engineer at KSC. This is in agreement with the present requirements for test procedural changes. After the pressure pulsing method was used to detank oxygen tank no. 2, the problem received further attention, including additional analyses and test. The Apollo team problem-solving effort that resulted was led by the MSC Apollo Spacecraft Program Manager and the KSC Director of Launch Operations. NR and Beech personnel were also involved. The MSC Apollo Spacecraft Program Office formulated a checklist of analyses to be made and questions to be answered prior to making the flight decision on the tank.

This included:

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 detanking problem?

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

7. Disassemble an oxygen tank on Service Module 2 TV-1 and examine components.

A detailed analysis, including possible failure modes, was made at Beech. Tests were run which indicated that even in the event of a loose metal fill tube (which was concluded to be the most likely cause of the detanking problem), a resultant electrical short would provide only 7 millijoules of energy and it was judged that this energy level could cause no damage except loss of the quantity gage indication. All of the checklist requirements were met by test or analysis prior to making the decision to fly without a change in the oxygen tank. It was jointly concluded by the Beech Apollo Program Manager, the NR CSM Program Manager, the KSC Director of Launch Operations, and the MSC Apollo Spacecraft Program Office (ASPO) Manager that the tank was flightworthy. Further examination of this event since the Apollo 13 accident, however, has revealed that incomplete and, in some cases, incorrect information was used in the decision process. This included:

1. Neither the KSC Launch Operations Director nor the MSC ASPO Manager knew of the previous tank handling incident at NR-Downey and neither knew that the oxygen tank internal heaters were on for 8 consecutive hours during detanking at KSC. Key personnel at NR-Downey knew of both events. No personnel at MSC, KSC, or NR knew that the tank heater thermal switches would not protect the tank from overheating.

2. A portion of the normal detanking process at Beech is similar to the normal detanking process at KSC. The KSC Launch Operations Director and MSC ASPO Manager were mistakenly informed that they were different. (If they had known of the similarity in detanking processes, they possibly would have concluded that some change took place in the tank between Beech and MSC.)

3. The KSC Launch Operations Director, the MSC ASPO Manager, and key personnel at Downey mistakenly understood that the oxygen tank on previous test Service Module 2 TV-1 had similar detanking problems which led to the decision to disassemble the 2 TV-1 tank and examine the components. That examination was interpreted as evidence that a loose-fitting metal fill tube probably was causing the detanking diffculty. Further examination has revealed, however, that 2 TV-1 oxygen tank probably detanked normally.

Although none of the principals in making the oxygen tank decision (NR, MSC, KSC) can say with certainty that the availability of information in 1, 2, and 3, above would have altered their decision, each concurs that the availability of such information could have altered their decisions.

On the basis of its review, the Project Management Panel feels the following observations to be pertinent:

1. Launch operations personnel did not fully understand the oxygen tank internal components or fully appreciate the possible effect of changed detanking procedures on the reliability of such internal components.

2. The hazard associated with the long heater cycle was not given consideration in the decision to fly this tank.

3. Problem solving during launch operations utilized telephone conferences among knowledgeable parties, but without subsequent written verification, which would have permitted more deliberate consideration and review.

4. Deviations from test procedures during tests at KSC were made in accordance with the established approval process. This does not require prior approval or concurrence of NR-Downey or MSC subsystem specialists.

5. It was found that insufficient consideration was given to the tank internal details such as sharp edges, internal wiring, and heater thermal switch ratings during the design reviews.

6. An historical record of the oxygen tank existed in the management system files. However, it was not referred to in making the flight decision.

7. Dependence upon memory of personnel led to erroneous data being reported to higher management levels.

8. Key Apollo management personnel made several suggestions during the Panel interviews:

(a) Provide total background history on subsystems which have problems or anomalies during launch operations.

(b) Launch operations personnel need more knowledge of the internal details of subsystems.

(c) NR (Downey) and MSC Subsystem Managers should review KSC test procedures and subsequent procedure changes.

(d) Verification of data is needed in problem solving.

(e) Followup documentation of information exchanged during telephone conferences on key problems is recommended.

Materials Compatibility

The compatibility of oxygen tank materials with oxygen received consideration in the original design. Beech reviewed and selected the tank materials in accordance with the published material knowledge that existed in the 1962-1963 time period. No data on hot-wire tests or ignition tests were available to Beech at that time. Beech ran special tests on the fan and motor assembly which was tested at 1000 psia in oxygen gas at 300° F. The motor passed this test with no evidence of ignition. Some attention was paid in the assembly procedures to avoid pulling wires over threads or sharp corners and to provide protective sleeving. However, most sharp corners were not eliminated and as was previously mentioned, the tank design necessitated a blind assembly with no way for subsequent inspection for damage. After the original design, Beech was not requested by NR to make any further materials compatibility study or tests. In April 1969, NR was directed by MSC to review the nonmetallic materials in the cryogenic oxygen subsystem and document them in accordance with the COMAT (Characteristics of Materials System). All nonmetallic materials in the oxygen tank were evaluated and documented by NR. All nonmetallic materials met the requirements of the materials control program. These materials criteria were specifically formulated for the lunar module and command module, where nonpropagation of fire was a requirement even if a fire started.

These COMAT requirements do not adequately cover the 900 psi cryogenic oxygen tank. No electrical ignition testing of any materials was made for the oxygen tank. NR reviewed the service module systems to provide electrical circuit protection such as breakers and fuses in 1967 in an effort to avoid electrical fires in case of shorts.

Security Program

During its review, the Panel also investigated the physical security at Beech, NR-Downey, and KSC for adequacy during the times the Apollo 13 oxygen tank was in custody at these locations. The security program at each location was found to be satisfactory and adequate to provide the physical protection of the oxygen tanks. A determination was made as a result of the survey that no evidence was discovered that the failure of the oxygen tanks on Apollo 13 was the result of any willful, deliberate, or mischievous act on the part of an individual at the facilities surveyed.

Safety and Reliability and Quality Assurance

A detailed management review was made of both the Safety and R&QA organizations as applicable to the Apollo CSM. Safety Offices at NASA Headquarters Office of Manned Space Flight, MSC, and KSC have safety responsibilities regarding Apollo which are clearly established and implemented by both Government and support contractor personnel. Safety audits by NASA Headquarters teams and participation by MSC and KSC personnel in panels, boards, and program reviews demonstrates continuing organizational attention to safety. Safety studies are being made to identify hazards associated with the Apollo spacecraft during ground tests and for each manned mission. NR-Downey has a safety organization with specific responsibilities for the Apollo CSM. The NR safety function is integrated into the Engineering, Manufacturing, and Test Operations with its objectives to eliminate or control risks to personnel and equipment throughout the manufacture, checkout, and flight missions of the Apollo CSM. Even though the NR safety effort, as written in their Safety Plan, is fragmented over several organizational units, it apparently is working effectively. In all cases, the safety organizations report to a sufficiently high organizational level to provide them a desirable independence of safety surveillance.

Failure Reporting

The Panel found that the Apollo Reliability and Quality Assurance organizations at MSC, KSC, NR, and Beech have an effective independent failure-reporting and failure-correction and tracking system. Documentation from this system was observed to be both rapid and accurate. The Reliability Group provides special studies such as Failure Modes and Effects Analysis (FMEA), Suspect Flight Anomalies Report, and configuration change tracking. In the case of the Apollo 13 oxygen tank, a Single Point Failure Summary was made in 1968. Among the failure modes considered was fire in the CSM external to the oxygen tanks which might lead to the loss of them. This was considered an acceptable risk because of control of ignition sources and low probability of occurrence. Rupture of the oxygen tanks was also considered and accepted due to the redundance of the oxygen supply and low likelihood of failure occurrence. For Apollo 13, as for previous missions, a System Safety Assessment was made on February 19, 1970, as an additional review from previous missions, and it was concluded that there were no open safety items to constrain the Apollo 13 flight.

PART E4

MANAGEMENT ORGANIZATION

Relating organizational and management structures to an event of the kind now under consideration is particularly difficult inasmuch as the time period of importance includes the entire history of the Program, in this case some 9 years, during which these structures have undergone many significant changes. With this in mind, the approach adopted for this study was (1) to examine and document what exists today, (2) to trace the history of events that might have had a direct bearing on the failure, (3) to examine the management inplications of those specific events, and (4) to try and assess whether those implications are still pertinent to management as it exists today and whether, therefore, corrective measures of any kind are indicated. To accomplish even this limited objective has required an early focusing of attention on just those organizations and functions directly involved, or potentially involved, in the events under consideration. Thus, following a brief description of the overall organizational and management relationships applicable to the Program as a whole, this report concentrates on those organizations responsible for the particular elements of the Apollo spacecraft in which the failure occurred.

BACKGROUND AND PERSPECTIVE

The Apollo Program has represented the largest single research and development program ever undertaken by the United States Government; at its peak (in 1966) it involved about 300,000 persons. The Government-industry team responsible for the Program has included 25 prime contractors and more than 4,000 subcontractors and vendors.

In its simplest terms, the Apollo Program has two major objectives: (1) to develop a vehicle capable of landing men on the surface of the Moon and returning them safely to the surface of the Earth, and (2) to operate that vehicle in an initial series of manned lunar landing missions. These two objectives have, in a gross sense, dictated the major division of responsibilities among NASA organizations in the management of the Apollo Program. With overall responsibility vested in the NASA Headquarters organization, responsibility for producing the vehicle was assigned to two NASA field installations:

1. For the spacecraft, to the Manned Spacecraft Center, Houston, Texas.

2. For the launch vehicle, to the Marshall Space Flight Center, Huntsville, Alabama.

The responsibility for operating the vehicle in the series of flight missions which constituted the second objective was also assigned to two field installations:

1. For launching the space vehicle, to the Kennedy Space Center, Cape Kennedy, Florida.

2. For all postlaunch operations, to the Manned Spacecraft Center, Houston, Texas.

These two major objectives also serve to classify the two major time periods into which the 9-year history of the Program can be divided. Thus, the first 7 years, from 1961 to 1968, constituted the development stage of the Program in which all components of the space vehicle, supporting equipment, and operational facilities were designed, developed, manufactured and tested; the last 2 years, from 1968 to the present, have constituted the beginning of the "operations" stage of the Program, with two successful manned lunar landing missions already achieved. The significance of distinguishing between these two periods of time lies in the inevitable shift of emphasis that accompanied the transition between the two from engineering problems to operational problems.

NASA - APOLLO MANAGEMENT ORGANIZATION

Two classical approaches to project management were available to NASA when the Apollo Program began in 1961. The first approach, often used by Government and the aircraft industry in the early years of aircraft development, would place in a single organization and under the total control of the project manager all of the skills and specialities required to manage the project. Thus, the project organization would provide for itself all the support necessary in engineering, procurement, program control, financial management, reliability and quality assurance, etc., and would operate virtually independently of the institutional organization of which it was a part. The second approach, which was rapidly gaining acceptance during the 1940's and 1950's, was the so-called "matrix" concept in which skeletal project management organizations were superimposed on an institutional organization containing elements and subelements in all of the specialities needed by the projects. Thus the institutional organization would provide the basic capabilities required by the projects in engineering, procurement, program control, etc., and the project managers would draw upon those as required. The advantages of this approach for multi-project organizations are apparent. Costly duplication of support activities is minimized, the overall efficiency of manpower utilization is maximized, and the quality of support provided is enhanced by consolidation.

NASA adopted the matrix approach to project management for the Apollo Program. In NASA Headquarters, and in each of the three principal NASA field centers involved, Apollo Program Offices were established from which virtually all of the direction for conduct of the Program has emanated. At each location, however, these Program Offices are essentially management organizations and depend heavily on the line elements of the host institution's organization for support. Continuity in lines of authority between the Apollo Program Director in Headquarters and the Apollo Program organization in the field has been assured through the delegation by each Center Director to his Apollo Program Manager of full authority for conduct of that Center's part of the Program. Thus, for purposes of program direction and authority, there exists throughout the Agency a single pyramidal management structure cutting across institutional lines and tying together all elements of the Apollo Program organization. This relationship is illustrated in figure E4-1.

The organizations of the principal NASA institutions involved in the Apollo Program are illustrated in figures E4-2 through E4-6, in which the locations of offices with primary responsibility for Apollo are indicated by heavy lines.

NASA Headquarters Organization

The Associate Administrator for Manned Space Flight, who heads the Office of Manned Space Flight, is the Administrator's executive agent for the general management of all manned space flight programs. His authority flows directly from the Administrator and is broad, covering all aspects of all manned space flight programs. He also exercises institutional line authority over the three manned space flight field centers which report directly to him.

Office of Manned Space Flight Organization

Figure E4-2 shows the organizational structure within the Headquarters Office of Manned Space Flight. The Associate Administrator for Manned Space Flight has assigned the responsibility for management of all aspects of the Apollo Program to the Apollo Program Director, and has delegated to him full authority to carry out that responsibility. The Apollo Program Director is the highest Agency official whose responsibility is exclusively for the Apollo Program. There are counterpart Program Directors for other manned space flight programs with similar responsibilities to their own programs, and there are a number of functional offices which, consistent with the matrix management concept, provide support to all on-going programs. Shown also in figure E4-2 are the direct lines of program authority between the Apollo Program Director and his subordinate program managers in the three field centers.

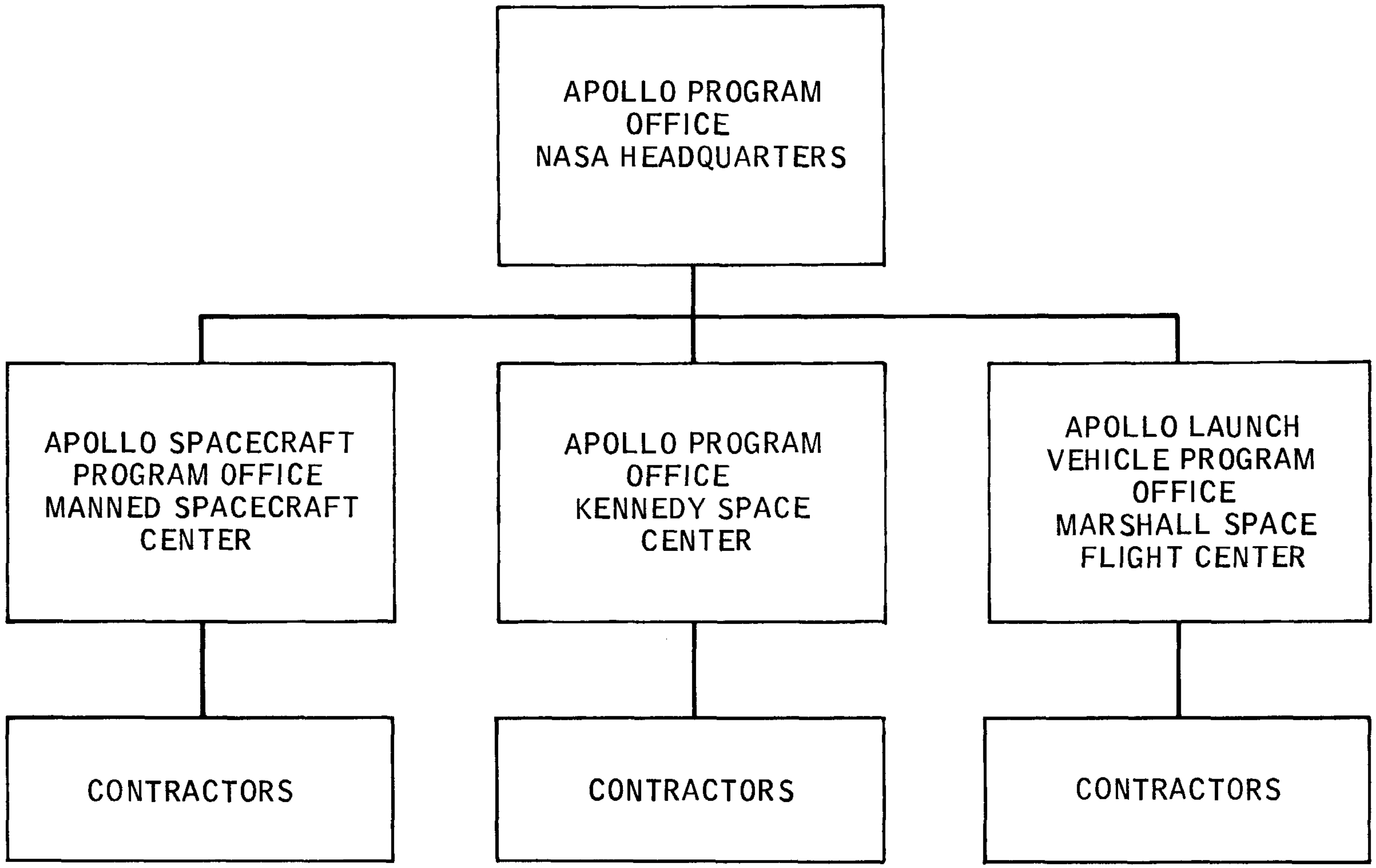

Figure E4-1.- NASA Apollo Program organization.

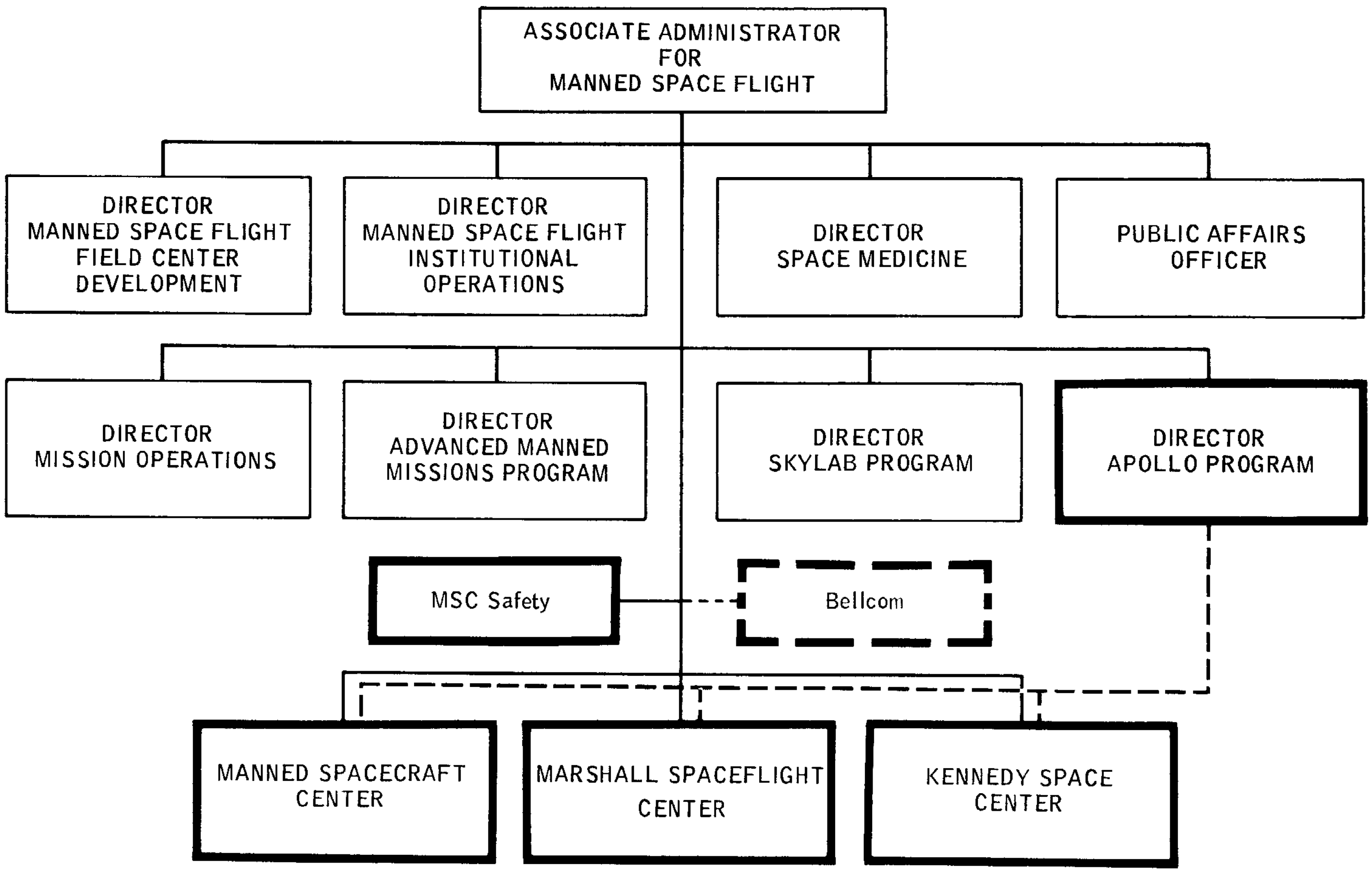

Figure E4-2.- Office of Manned Space Flight organization.

Manned Spacecraft Center (MSC)

The organization of the Manned Spacecraft Center is shown in figure E4-3. The permanent functional organizations are represented by the five technical directorates (Engineering and Development, Science and Applications, Medical Research and Operations, Flight Crew Operations, and Flight Operations) and the institutional Directorates and Staff Offices (e.g., Administration, Program Control and Contracts, Public Affairs, Legal, etc.). The program management organizations presently include the Apollo Spacecraft, Skylab, and Space Shuttle Program Offices, and the Advanced Missions Program Office, which is responsible for studies and planning potentially leading to new flight programs.

Responsibility for managing all aspects of the Apollo Program assigned to the Center is vested in the Manager of the Apollo Spacecraft Program Office (ASPO). Under the matrix-management concept, a relatively small percentage of the Center's staff directly employed in the Apollo Program reports to him organizationally. Virtually all of the Apollo tasks done in-house at MSC (component testing, instrumentation development, flightcrew training, operations planning, etc.) are performed by the Center's line organizations (the functional Directorates) under the overall direction and coordination of the ASPO Manager.

Marshall Space Flight Center (MSFC)

This Center is responsible for the development, manufacture, and testing of the launch vehicles used in the Apollo Program. The organization of the Center is shown in figure E4-4. As at MSC, this Center employs the matrix-management concept in which the basic organization, represented by the Program Development, Science and Engineering, and Administration and Technical Services Directorates, is functional and the program-management organization, represented by the Program Management Directorate, is made up of program offices for individual launch vehicles or stages.

Although the Saturn Program Office represents the Apollo Launch Vehicle Program Office for purposes of full-time management, the Director of Program Management has been designated the Apollo Launch Vehicle Program Manager. He manages and directs all aspects of the Apollo Program assigned to MSFC, drawing on technical support from the Science and Engineering Directorates.

Kennedy Space Center (KSC)

The KSC responsibility in the Apollo Program includes the assembly, checkout, and launch of the space vehicle.

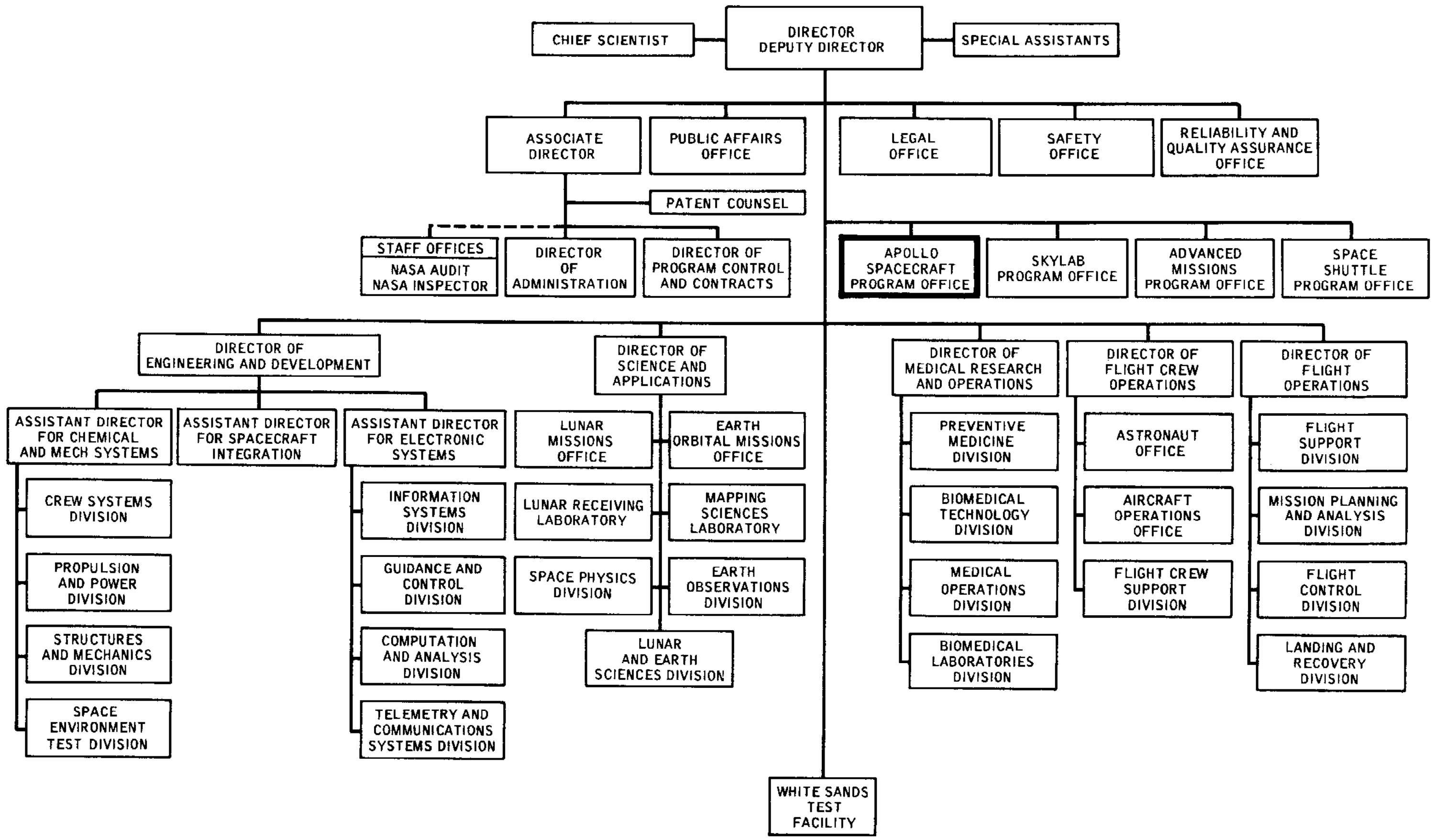

Figure E4-3.- Manned Spacecraft Center organization.

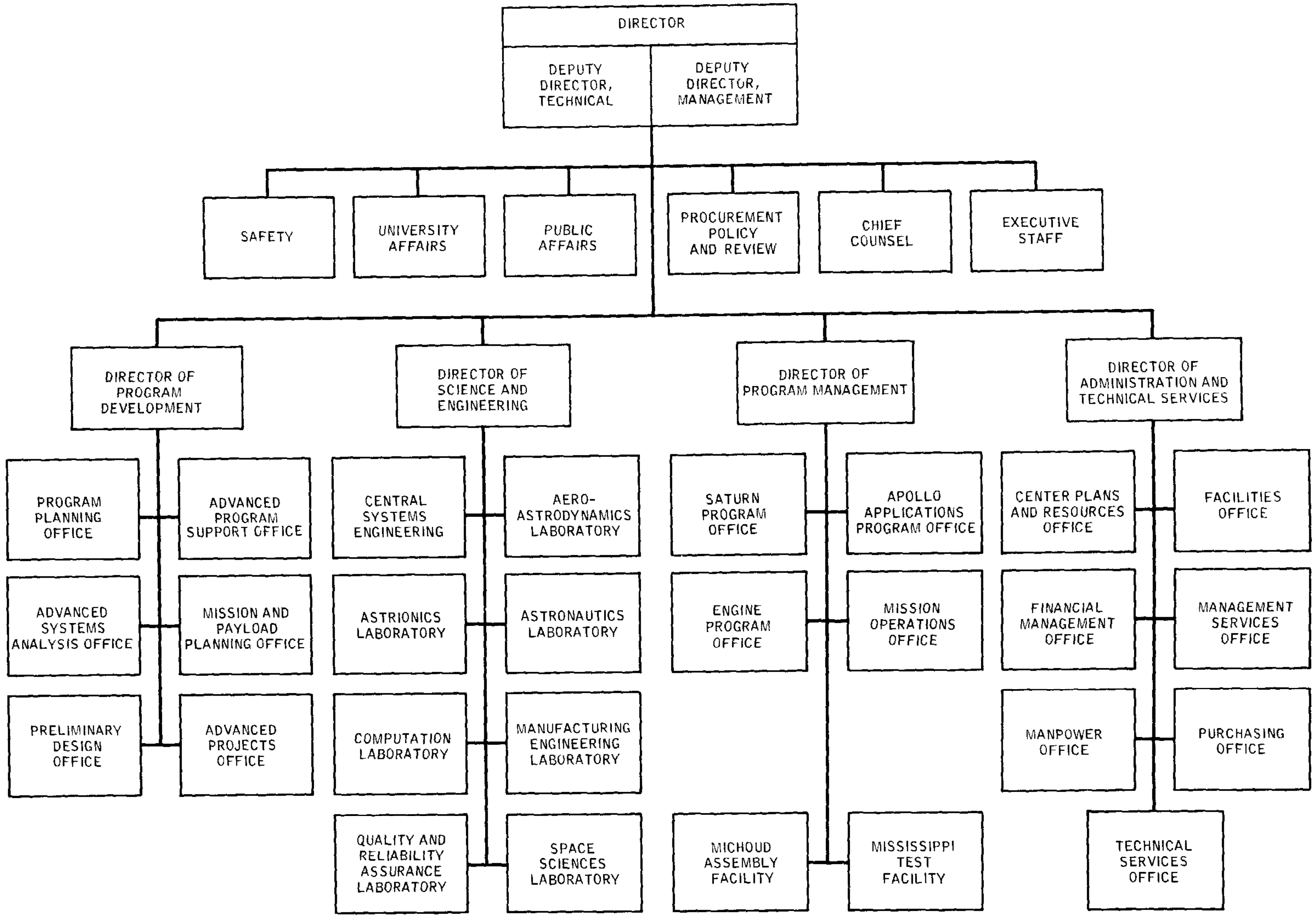

Figure E4-4.- Marshall Space Flight Center organization.

The organization of the Center is shown in figure E4-5. Again the basic organization is functional, consisting of those major operational activities necessary to the launch of all space vehicles. The program-management organization is similar to that at MSC and is made up of an individual program office for each active flight program. Overall responsibility for managing all aspects of the preparation, checkout, and launch of the Apollo space vehicles is assigned to the Manager of the Apollo Program Office (APO). All functional organizations at the Center participate in those activities under the overall direction of the APO Manager. Direct responsibility for launch and checkout is delegated to the Director of Launch Operations.

CONTRACTOR ORGANIZATIONS

The oxygen tank in which the failure occurred was a component of the cryogenic gas storage subsystem (CGSS), which serves both the electrical power system (EPS) and the environmental control system (ECS) of the spacecraft service module (SM). The contractors and contractual relationships involved in the manufacture of the tank are illustrated in figure E4-6. North American Rockwell (formerly North American Aviation), prime contractor for the command and service modules (CSM), subcontracted with Beech Aircraft Corporation for manufacture of the CGSS. Beech, in turn, purchased certain parts for the subsystem from the three vendors shown: the oxygen pressure vessel (inner tank) from Airite Products Division of the Electrada Corporation; the oxygen quantity and temperature sensor probe from Simmonds Precision Products, Inc.; and the fan motors from Globe Industries, Inc. Pertinent organization charts for North American Rockwell and Beech Aircraft are shown in figures E4-7 through E4-11. The organizations of the vendor companies were not considered pertinent and are not shown.

North American Rockwell (NR)

The Apollo CSM contract is held by the Space Division of North American Rockwell and the organization of that Division is shown in figure E4-7. North American Rockwell also applies the matrix-management concept in their current organization with program offices (Saturn S-II, Space Station, CSM, Space Shuttle, etc.) superimposed on a basically functional organizational structure which includes Manufacturing, Research, Engineering, and Test; Material; Quality and Reliability Assurance; and the conventional administrative-support functions. The Apollo contract is managed for NR by the CSM Program Office headed by a division vice president. Figure E4-8 shows the organization of that Office. Within the CSM Program Office the principal suborganization for program management is Engineering, headed by an Assistant Program Manager and Chief Program Engineer. On the functional side of the Space Division, referring again to figure E4-7, line responsibility for

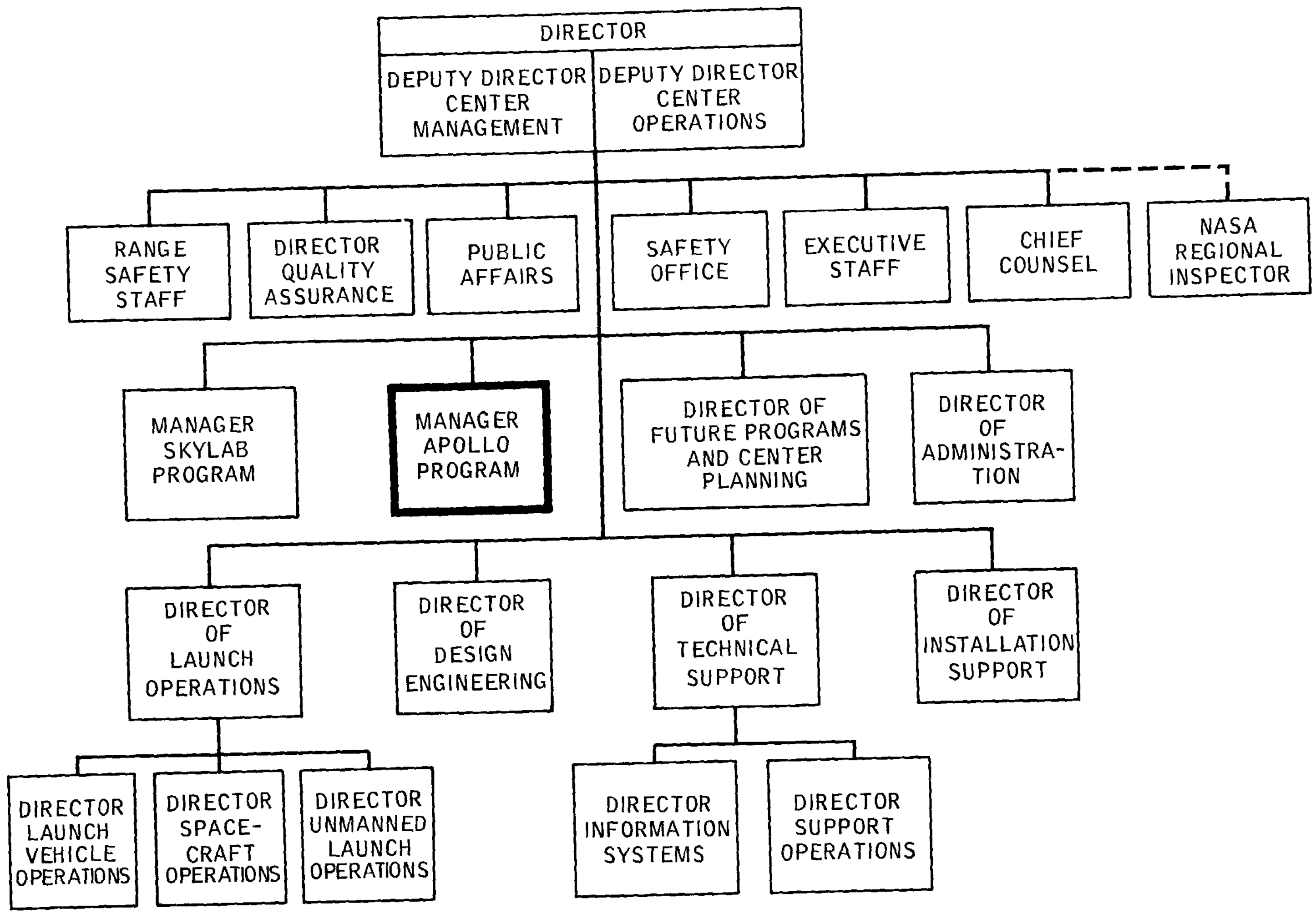

Figure E4-5.- Kennedy Space Center organization.

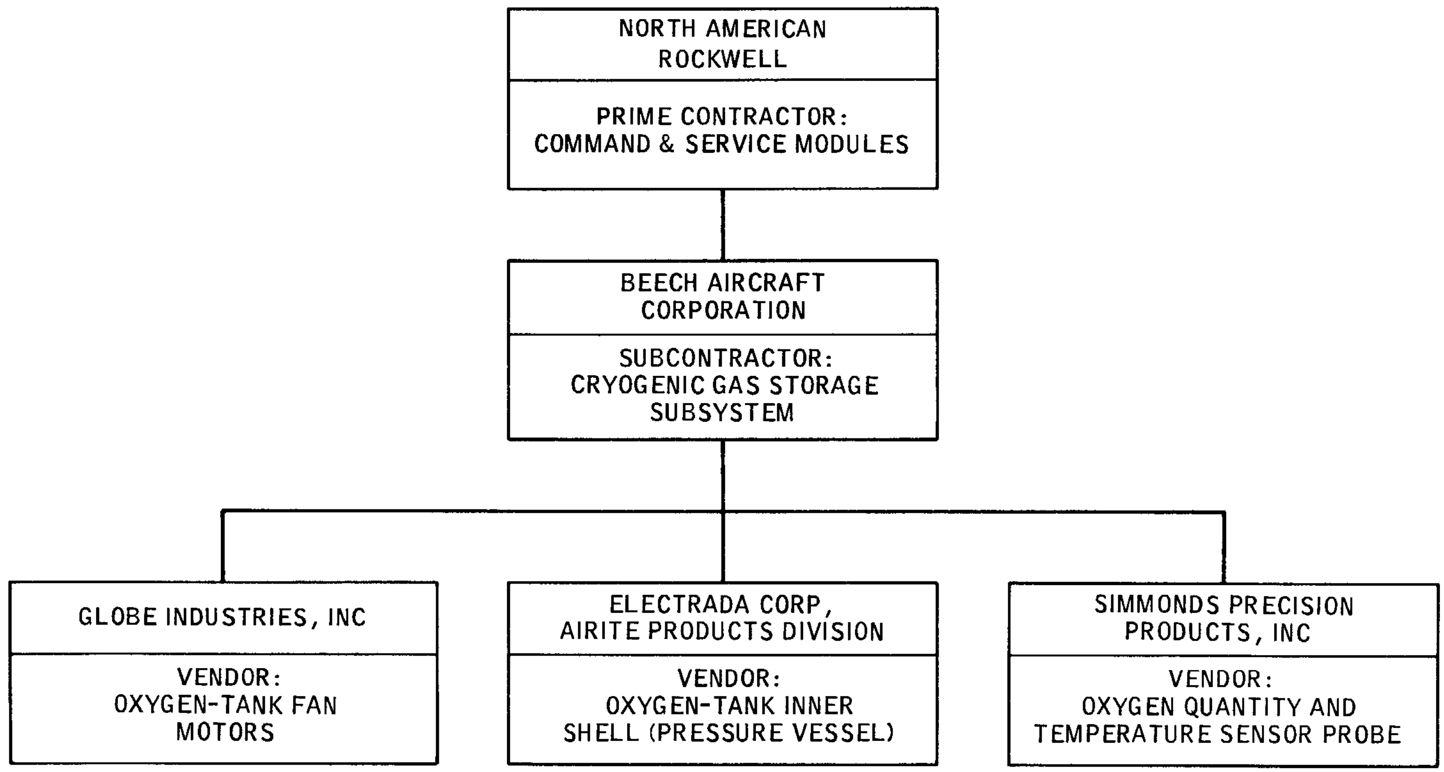

Figure E4-6.- Croygenic gas storage subsystem-contractual relationships.

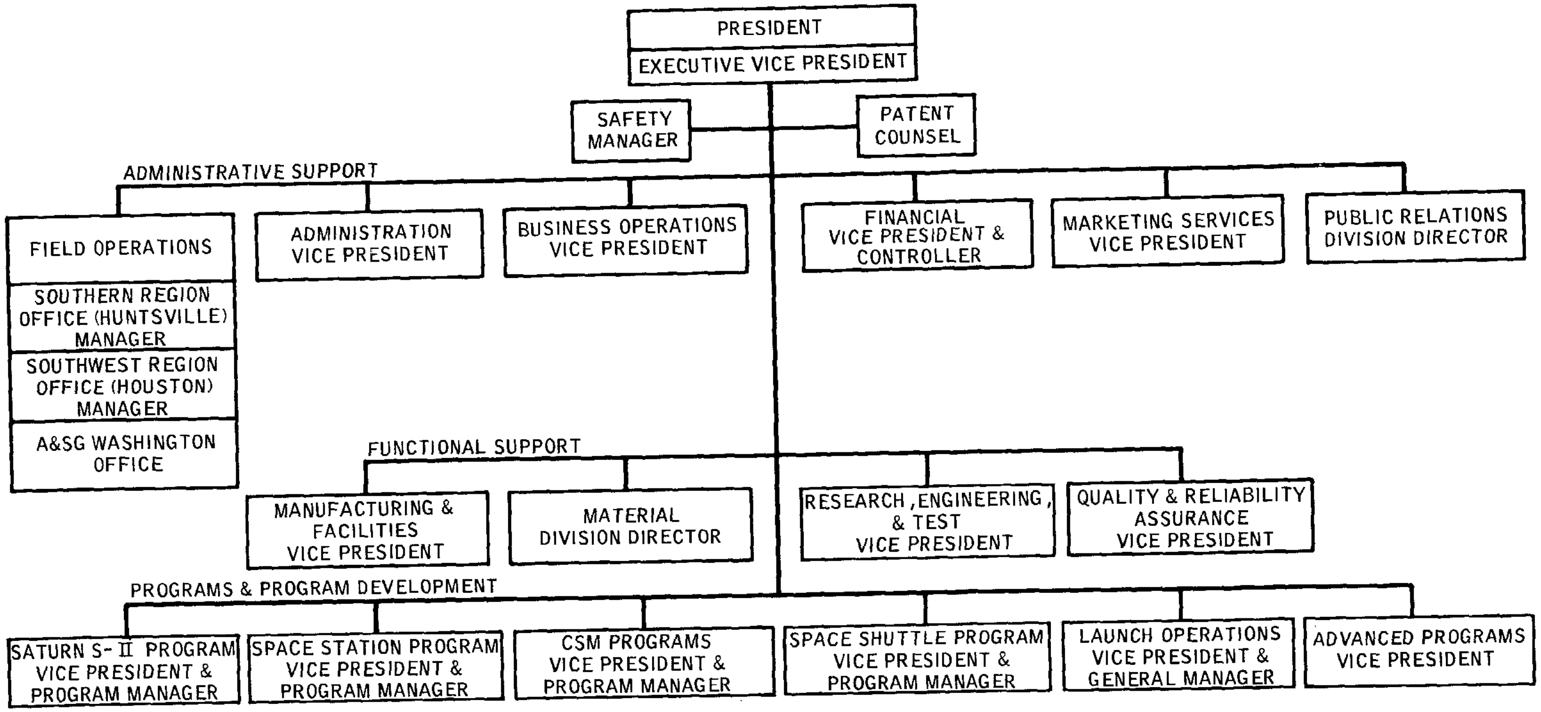

Figure E4-7.- North American Rockwell, Space Division organization.

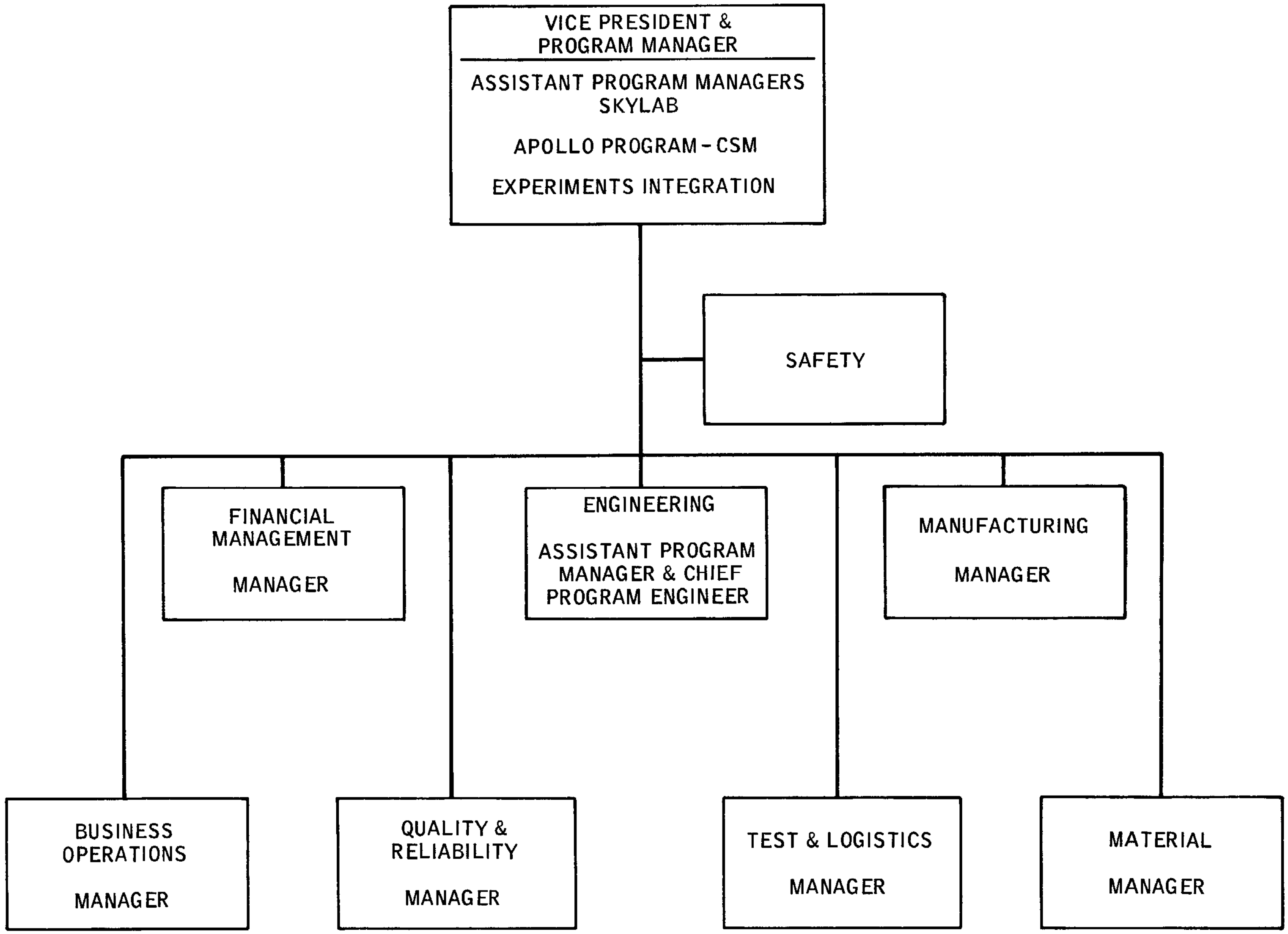

Figure E4-8.- North American Rockwell, Space Division, CSM Programs Office organization.

performance (as opposed to management) under the Apollo contract falls under the functional support organization for Research, Engineering, and Test, also headed by a division vice president. The organization of that Office is along systems/subsystems lines. At the subsystem level, the engineer in charge in this organization also acts as the subsystem manager for the program management organization, in a manner quite analogous to the technique used by the MSC organization described earlier. The relationship at North American Rockwell is illustrated in figure E4-9.

North American Launch Operations Space Division (KSC)

All NR CSM operations at KSC are conducted in accordance with the provisions of Supplement KSC-1 to MSC contract no. NAS9-150 with NR. The Supplement contains a statement of work prepared by KSC and KSC is responsible for technical direction to the NR personnel. The NR Apollo CSM Operations at KSC supports KSC in CSM checkout and launch and is a part of the NR Launch Operations Space Division under the NR Vice President and General Manager who is located at Cocoa Beach, Florida. He, in turn, reports to the Space Division President, NR.

Beech Aircraft Corporation

The subcontract from North American Rockwell, for manufacturing of the cryogenic gas storage subsystem, is held by the Boulder Division of the Beech Aircraft Corporation. The organization of that Division is shown in figure E4-10. Beech also uses the matrix-management concept with management responsibility for the Apollo subsystem contract vested in the Apollo Program Manager and performance responsibility in the Manager, Engineering. Figure E4-11 shows the breakdown of management responsibilities within the office of the Apollo Program Manager.

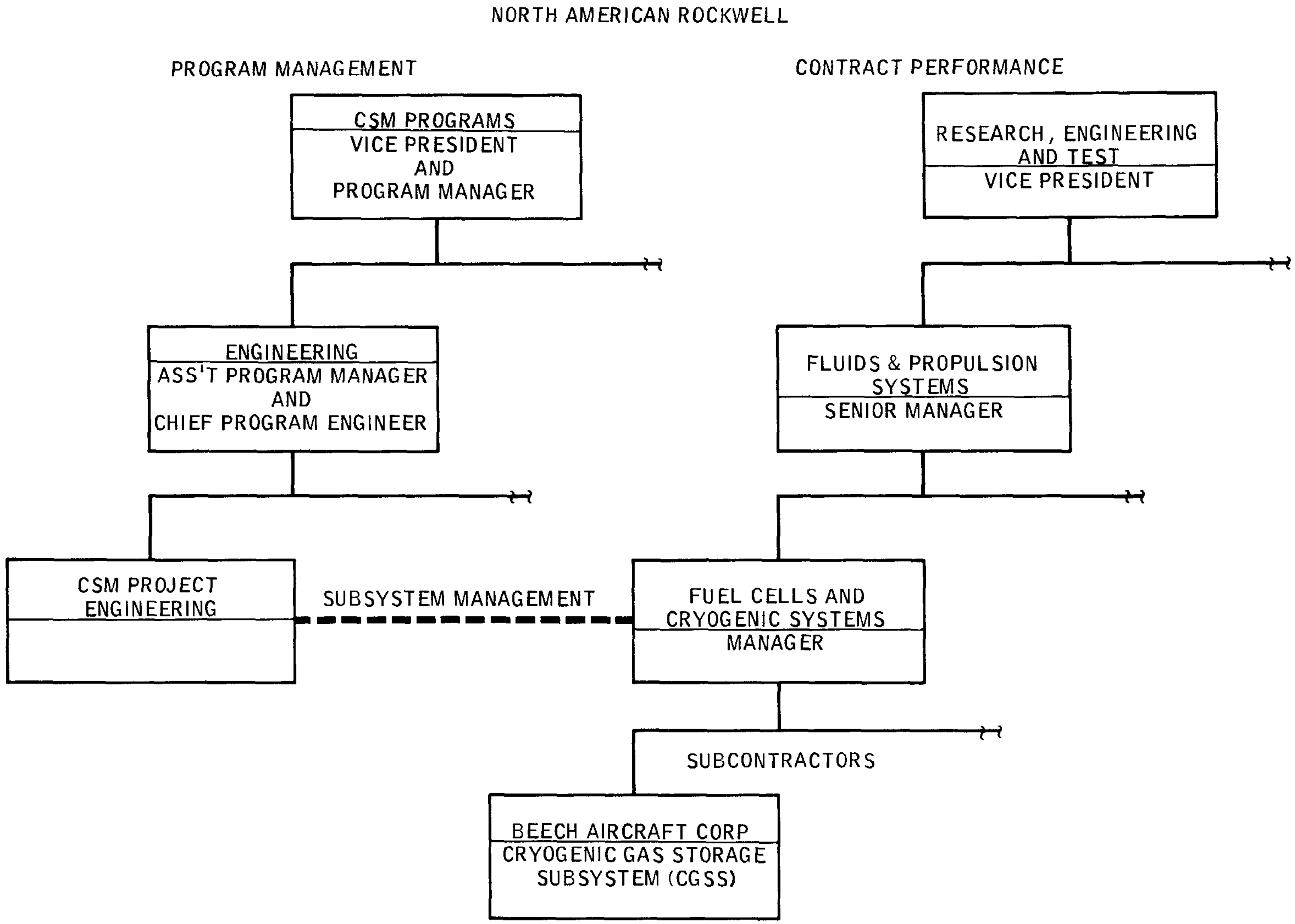

Figure E4-9.- North American Rockwell organizational relationships applicable to cryogenic gas storage subsystem.

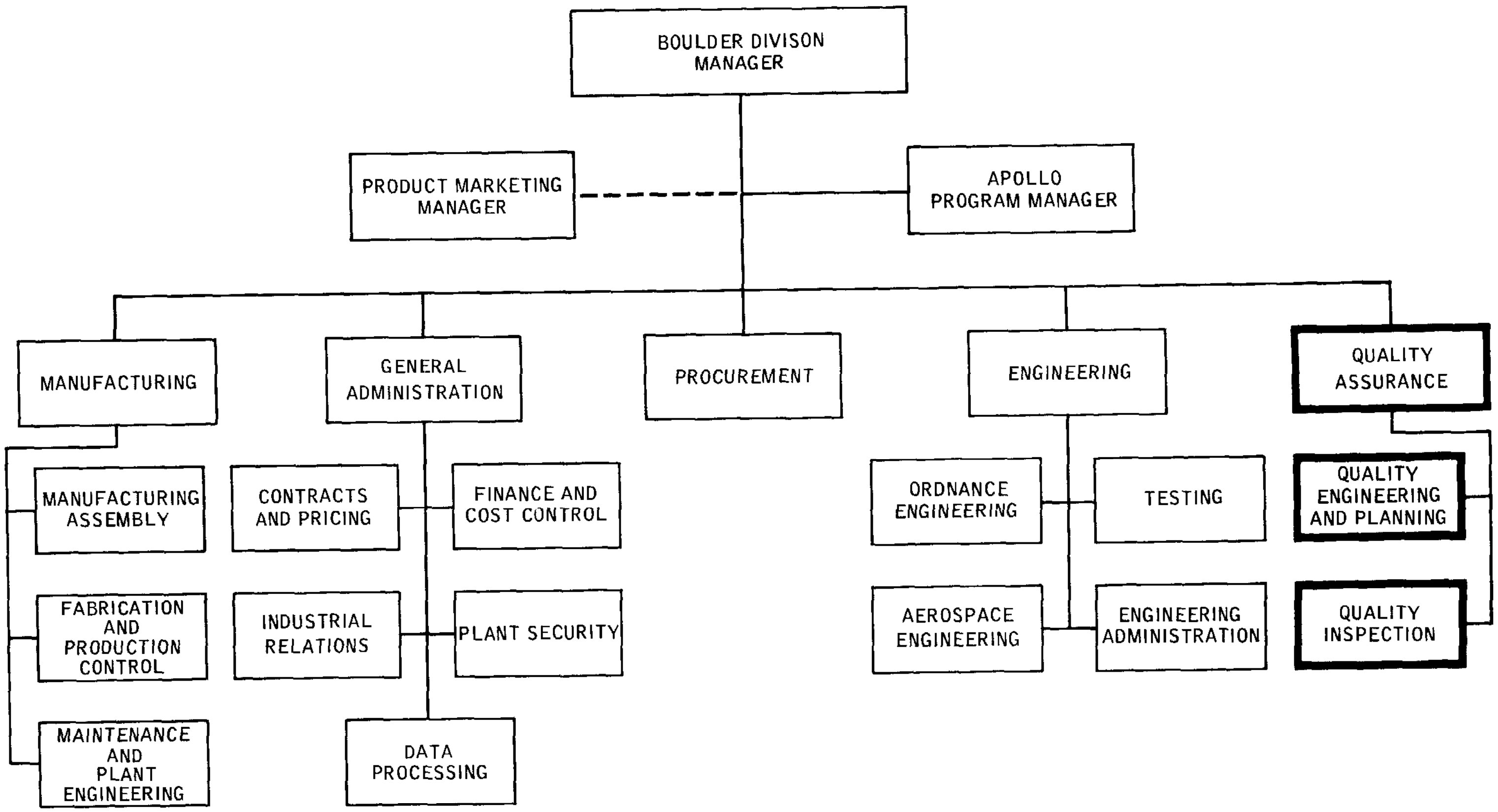

Figure E4-10.- Beech Aircraft Corporation organization.

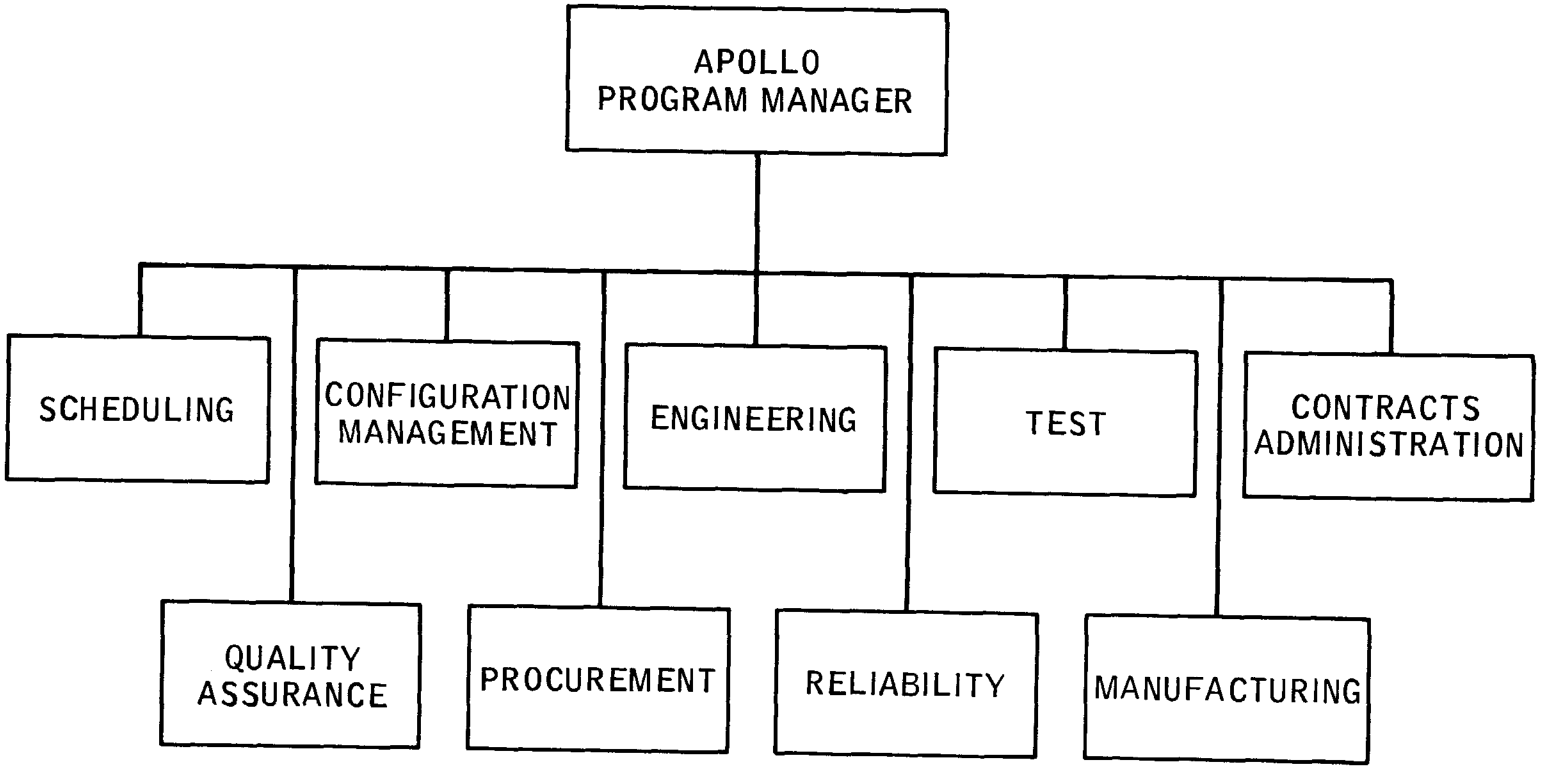

Figure E4-11.- Beech Aircraft Corporation, Boulder Division, Apollo Program Office organization.

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PART E5

RESPONSIBILITIES AND OPERATING RELATIONSHIPS

The specific responsibilities assigned to most of the NASA organizational elements involved in management of the Apollo Program are described in some detail in the series of documents titled NASA-Apollo Program Management. Where those descriptions are still pertinent, they are incorporated here by reference or are paraphrased as necessary to maintain the continuity of this document. The following discussion is, for the most part, confined to those organizations and responsibilities that are germane to the present study.

NASA ADMINISTRATOR

The Administrator of NASA reserves to his own office the authority for establishing and enforcing Agency policy, for establishing overall program policy and objectives, for approving mission plans and schedules, for mission funding and major procurement actions, and for insuring adherence to functional management policies. Apollo Program policies, objectives, and management systems are reviewed and approved by the Administrator, as are significant schedule and budget decisions. Management directives relating to the Program are issued within the Agency-wide NASA Issuance System, with special provisions for specific instructions and directives to be issued by the Apollo Program Director to participating program elements in the Manned Space Flight Field Centers.

ASSOCIATE ADMINISTRATOR FOR MANNED SPACE FLIGHT

As described earlier, the Associate Administrator for Manned Space Flight, serving as the Administrator's executive agent for the general management of all manned space flight programs, shares full responsibility with the Administrator for all aspects of these programs. In this capacity, he is advised by three major policy bodies: the Manned Space Flight Management Council, the Science and Technology Advisory Committee, and the Manned Space Flight Experiments Board. The responsibilities of these groups are summarized as follows.

Manned Space Flight Management Council

The Council consists of the Associate Administrator for Manned Space Flight as Chairman and the Directors of the three Manned Space Flight Centers. The Associate Administrator for Manned Space Flight establishes program policy guidelines and program plans in consultation with the Council. For the Apollo Program, the Council reviews policy, progress, and performance to assure that goals are being met, that technical problems are being dealt with properly, and that adequate resources are available for conduct of the planned program. The Council also acts as the Design Certification Board in examining the entire Program for proof of development maturity prior to each manned flight of a new configuration. To insure flightworthiness and manned flight safety, the Council assesses the design of the space vehicle launch complex, the Mission Control Center, the Manned Space Flight Network, and the launch instrumentation for manned Apollo missions. A Mission Design Certification Document, executed by the entire membership of the Council, serves as the approval authority for proceeding with specific flight missions designated for manned flight.

Science and Technology Advisory Committee

The Committee is made up of leading scientists and engineers from universities, industry, and Government. The Committee functions in an advisory capacity to the Associate Administrator for Manned Space Flight on major technical and scientific questions. They perform independent evaluations and make recommendations to the Associate Administrator for Manned Space Flight.

Manned Space Flight Experiments Board

The Board consists of the Associate Administrator for Manned Space Flight as Chairman, the Associate Administrators for Space Science and Applications and for Advanced Research and Technology, and representatives from the Department of Defense and the Air Force. The Board's responsibility is to advise and recommend to the Associate Administrator for Manned Space Flight which experiments should be included in manned space flight missions.

APOLLO PROGRAM DIRECTOR

Full responsibility and authority for managing all aspects of the Program within the constraints of budget, schedule, and performance approved by the Administrator are delegated to the Apollo Program Director by the Associate Administrator for Manned Space Flight. It is the Program Director's responsibility to define or approve mission requirements, technical requirements, program specifications, and reliability, quality assurance, and safety standards. His office is organized into the five functional Directorates shown in figure E5-1. The Apollo Program Offices in the three Manned Space Flight Centers have organizational structures similar to that of the Program Director's, thus providing parallel responsibilities for managers at the two levels. The responsibilities of four of the five Directorates in the Apollo Program Office are described in the following paragraphs.

Test Directorate

The Test Directorate is responsible for planning and coordinating development of test programs for all phases of design, manufacture, and checkout of launch vehicles, spacecraft, experiment hardware, and ground support equipment. The Directorate coordinates requirements for test facilities, and prepares and justifies budget requests for test programs and facilities.

Operations Directorate

The Operations Directorate is responsible for operations plans and schedules; operations documentation; mission test plans; flight plans; trajectory design and analysis; crew operations and training; premission operations checkout, mission safety, and hazard probabilities; and mission operations support.

Systems Engineering Directorate

The Systems Engineering Directorate is responsible for developing the Apollo Program Specifications; developing flight mission assignments (including mission objectives and overall flight profiles); reviewing program to define technical interfaces; establishing control weights for vehicle stages and spacecraft modules; and verifying that system performance requirements are achieved.

Program Control Directorate

The Program Control Directorate is responsible for integrated planning; preparation of Program Development Plans; maintaining interrelated schedules; logistics; specifications; performance analysis and control system management; configuration management; data management systems;

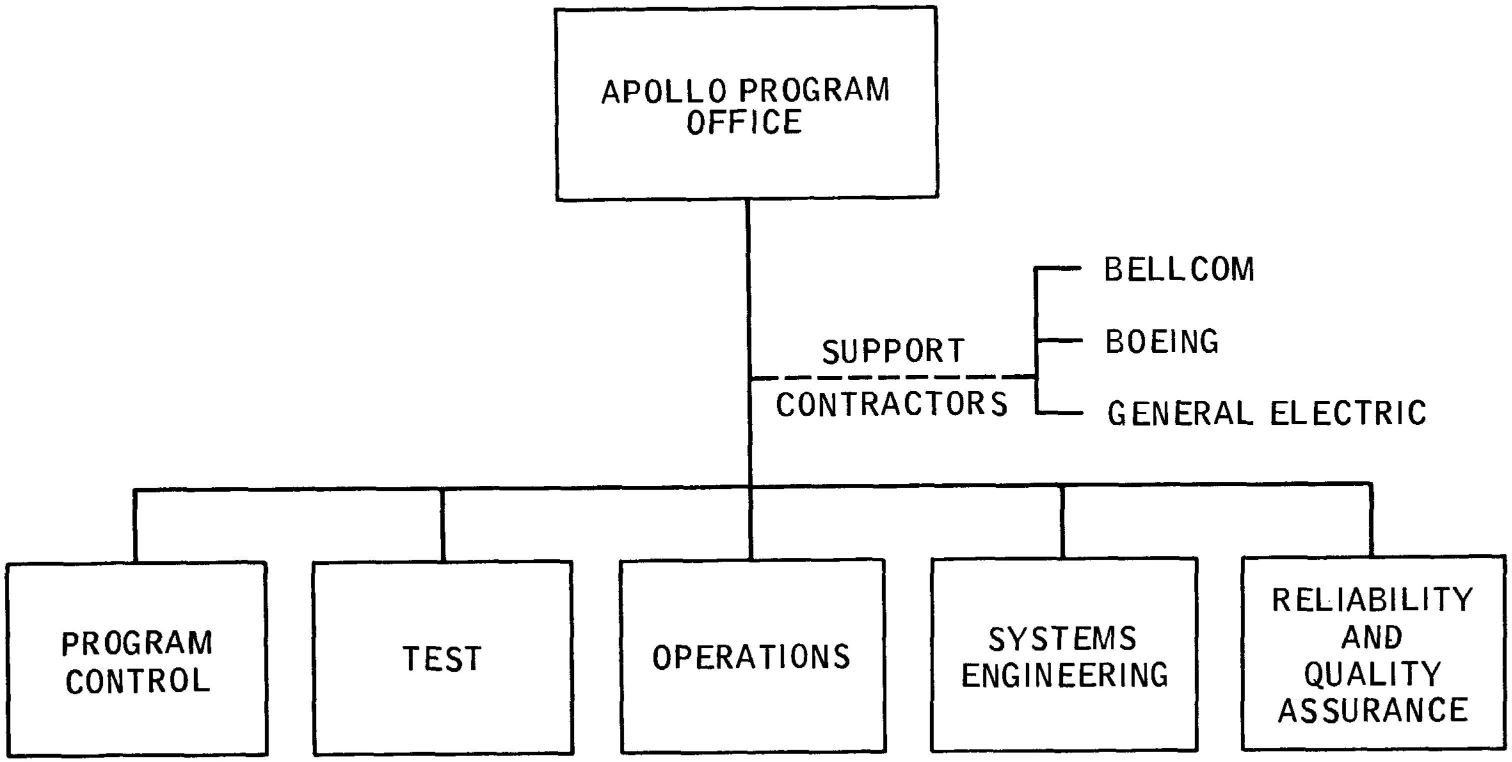

Figure E5-1.- Functional organization of the Apollo Program Office, NASA Headquarters.

preparation of budget and cost information; and operation of the Apollo Action Center.

Reliability and Quality Assurance (R&QA) Directorate

The R&QA Directorate is responsible for initiating program-wide R&QA policies and procedures; preparing program development plans for the Manned Space Flight Centers; developing R&QA training programs; establishing R&QA reporting requirements; and evaluating the effectiveness of R&QA programs in the Centers.

Support Contractors

The Apollo Program Director also has the services of three support contractors available to him:

1. Bellcomm, Inc. (AT&T), which provides systems engineering support consisting of studies, technical evaluations, analytical investigations, and technical consulting services.

2. The Boeing Company, Space Division, which performs the technical integration and evaluation function for the Program Director. This includes analyses and evaluation of program management, interface control, configuration management, logistics, engineering, manufacturing, testing, launch operations, and information systems.

3. General Electric Company, Apollo Systems Development, which provides general engineering support, including data management, management information systems, and R&QA investigations.

MSC APOLLO SPACECRAFT PROGRAM OFFICE (ASPO)

As in the Headquarters organization, the Apollo Spacecraft Program Manager at MSC acts for the MSC Center Director as general manager of all Apollo-related activities at the Center. In that capacity he is the official technical interface between NASA and the spacecraft contractors. He is responsible for managing the accomplishment of all Apollo tasks at the Center, even though many of those tasks are performed by Center personnel not organizationally responsible to him. His functional responsibilities essentially parallel those of the Apollo Program Director, but are applicable to the spacecraft only while those of the Program Director encompass all aspects of the Program. His Program Office organization is also essentially parallel to that of the Program Director's, as shown in figure E5-2. He has delegated to three subordinate Managers (for the CSM, the LM, and Experiments and GFE) the following responsibilities:

1. Directing the design, development, and fabrication programs carried out by the contractors.

2. Directing and planning systems engineering and systems integration functions, including review of engineering design and systems engineering studies conducted by the contractors.

3. Developing the ground- and flight-test programs to be conducted at White Sands, MSC, and KSC.

4. Monitoring contractor operations to assure adherence to specifications and to identify and solve problems in the development and fabrication of systems and subsystems.

5. Chairing the Configuration Control Board (Level 3).

Assistant Program Manager for Flight Safety

There is also within the Apollo Spacecraft Program Office an Assistant Program Manager for Flight Safety, whose responsibility is to assure that the policies and procedures of MSC's Safety Office are adhered to in all Apollo Program activities relating to the spacecraft. He is the Apollo Spacecraft Program Manager's Safety representative to KSC and the spacecraft contractors. He oversees all program activities from a flight safety viewpoint and is an advisor to the Program Manager on the flightworthiness of all systems.

Systems Engineering Division

Referring again to figure E5-2, there are six functional divisions reporting to the Apollo Spacecraft Program Manager. Two of these perform functions that have a direct bearing on the development and manufacture of the cryogenic gas storage subsystem. The Systems Engineering Division is responsible for the coordination and control of the design and development of all spacecraft systems. The Division determines the technical requirements, and develops technical specifications (with the contractor) for systems and subsystems, and is responsible for assuring that all program elements (crew, hardware, and software) are successfully integrated into each system design. This Division plays its major role during the design and development stage of the spacecraft and its systems. It is responsible for organizing and conducting all Preliminary Design Reviews and Critical Design Reviews. It is also responsible

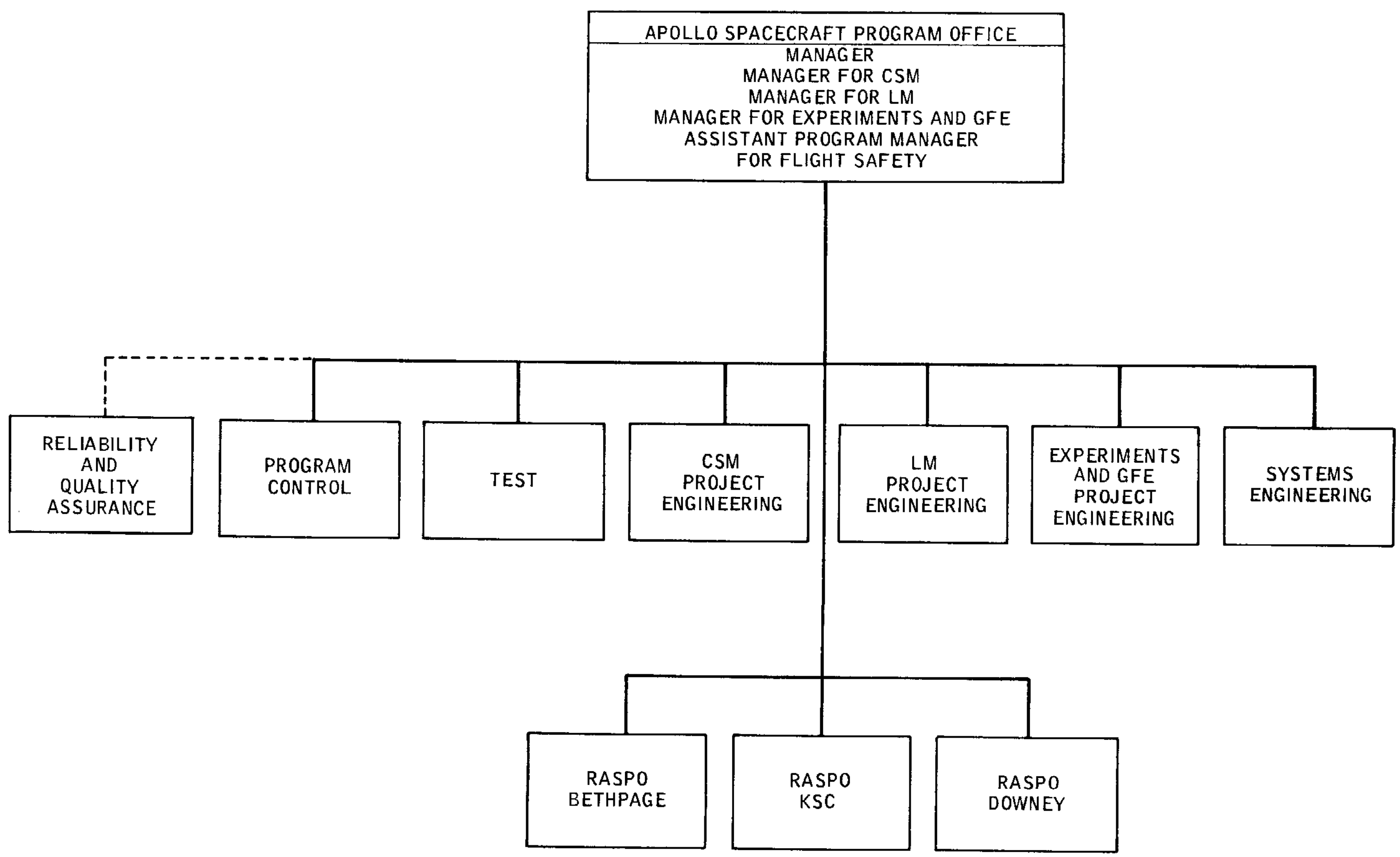

Figure E5-2.- Functional organization of the Apollo Spacecraft Program.

for definition and implementation of the nonmetallic materials program. Mission definition and planning are also major responsibilities.

CSM Project Engineering Division

This Division, which has counterpart Divisions for the LM and for Experiments and GFE, plays its major role during manufacture and test of the spacecraft. From this Division two engineers, designated as Project Engineers, are assigned to each spacecraft as it begins manufacture. The Project Engineers are the Program Manager's representatives for his particular spacecraft and are responsible for assuring that that particular spacecraft is ready for launch on schedule, that it has successfully passed all tests, inspections, and reviews, and that all associated ground support equipment is on schedule. Their responsibility extends up to launch and resumes after recovery for postflight testing.

Resident Apollo Spacecraft Program Offices (RASPO)

There are Resident Apollo Spacecraft Program Managers at the North American Rockwell plant, Downey, California (for the CSM prime contract), at Bethpage, New York (for the LM prime contract), and at the Kennedy Space Center (for launch activities). The Managers of the RASPO-Downey and the RASPO-Bethpage act for the Apollo Spacecraft Program Manager in all spacecraft activities taking place at their locations. Their responsibilities encompass program control, manufacture, test and checkout, and configuration management. The Manager at the RASPO-Kennedy represents the Apollo Spacecraft Program Manager in all operations at KSC which relate to the spacecraft. Specific responsibilities include:

1. Liaison with the KSC Spacecraft Operations Director on all matters relating to spacecraft preparation and checkout for launch.

2. Submission to KSC of MSC's prelaunch test and checkout requirements for the spacecraft.

3. Approval of KSC's Test and Checkout Plans.

4. Approval of waivers and deviations to MSC's test and checkout requirements.

5. Restricted change approval related to GSE and test operations.

MSC RELIABILITY AND QUALITY ASSURANCE (R&QA) OFFICE

The R&QA Office at MSC is an independent functional office reporting to the Director of the Center and responsive to the ASPO. It has overall responsibility for planning, coordinating, and directing all R&QA activities at the Center. Specific responsibilities include:

1. Establishing reliability, quality, and inspection requirements and criteria for spacecraft, systems, subsystems, and supporting equipment.

2. Insuring implementation of R&QA requirements and criteria at contractor plants and at MSC.

3. Developing MSC engineering design standards and criteria.

4. Establishing certification test criteria and approving certification test plans and reports.

5. Establishing and enforcing policies governing parts and materials identification, usage, and qualification information for critical spacecraft hardware.

MSC SAFETY OFFICE

The Safety Office at MSC is also an independent functional office, reporting to the Center Director. It is responsible for establishing safety policies, standards, and procedures in the fields of industrial operations and manned space flight. Specific responsibilities include:

1. Review and evaluation of the safety of operations in all Center organizations.

2. Advising the Center Director and Center Management on all matters relating to industrial and flight safety.

3. Reviewing and evaluating the effectiveness of contractor safety programs against MSC safety standards and criteria.

MSC ENGINEERING AND DEVELOPMENT DIRECTORATE

The Engineering and Development Directorate is the principal engineering component of the Center functional organization. This Directorate, organized into Divisions by technical discipline, conducts most of the Center's supporting research and technology, develops concepts for advanced systems, and provides technical support to all ongoing flight programs. This support roughly subdivides into three major categories:

1. Systems analyses and definition of new techniques applicable to space flight programs.

2. Subsystem and component tests.

3. Technical management of the design, manufacture, and testing of subsystems by the Program contractors.

This latter function represents a major element of the Apollo Program management system and is described as follows:

The three subordinate Managers in the ASPO (for CSM, LM, and Experiments and GFE) rely heavily on the matrix management concept for carrying out their responsibilities. They receive technical support from subsystem managers appointed from the technical Directorates of the Center's line organization. There are between 40 and 50 subsystem managers, most of them located in the Engineering and Development Directorate (fig. E4-4). The Subsystem Manager for the cryogenic gas storage subsystem is organizationally located in the Propulsion and Power Division of that Directorate. These managers remain assigned to their permanent organizations, but assume program responsibility for the design, development, and manufacture of particular subsystems. In this role they report to the Module Manager (e.g., Manager for the CSM) in the Program Office. For all other purposes they report through normal organizational lines. The subsystem manager's responsibility for his subsystem is continuous from preliminary design through operations. He is the Program Office's technical manager of all work done on the subsystem (although contractor direction is given through the Project Officer or Contracting Officer) and is responsible for assuring that the subsystem is built on schedule, within budget, and to specifications.

KSC APOLLO PROGRAM MANAGER

The Apollo Program Manager at KSC represents the Center Director in all matters relating to the launch of an Apollo space vehicle. He develops all necessary plans for work to be accomplished at KSC for the Apollo Program and issues "requirements" to the line organizations of the Center. The line organizations then assume full responsibility for conducting their parts of the Program, and the role of the Apollo Program Manager becomes one of monitoring, assessing, and modifying requirements as necessary. The organization of the KSC Apollo Program Office is shown in figure E5-3.

KSC DIRECTOR OF LAUNCH OPERATIONS

This organization has the principal functional responsibility for conducting the launch of the Apollo space vehicle. The Director of Launch Operations is responsible for the management and technical direction of preflight operation and integration, assembly, test, checkout, and launch of all space vehicles. He initiates, supervises, and coordinates the preparation of preflight and launch operations test plans and assures their effective execution. He assists the Apollo Program Manager in negotiating test and operational sequences, methods, and standards with the two development Centers (MSC and MSFC).

INTER-CENTER RELATIONSHIPS

Because the day-to-day management of the Apollo Program, from design through launch, requires close coordination of activities underway at three field Centers and in NASA Headquarters, formally documented Inter-Center Agreements have been drawn to specify how responsibilities are divided and how the activities at each location relate to those at the others. Additionally, a series of Inter-Center Coordination Panels has been established which recommend solutions to technical interface problems involving the responsibilities of two or more Centers. There are eight such panels, covering: Crew Safety, Electrical, Flight Evaluation, Mechanical, Instrumentation and Communications, Flight Mechanics, Launch Operations, and Flight Operations. All panels operate under the cognizance of a Panel Review Board made up of representatives from the three Manned Space Flight Centers and the Headquarters Office of Manned Space Flight.

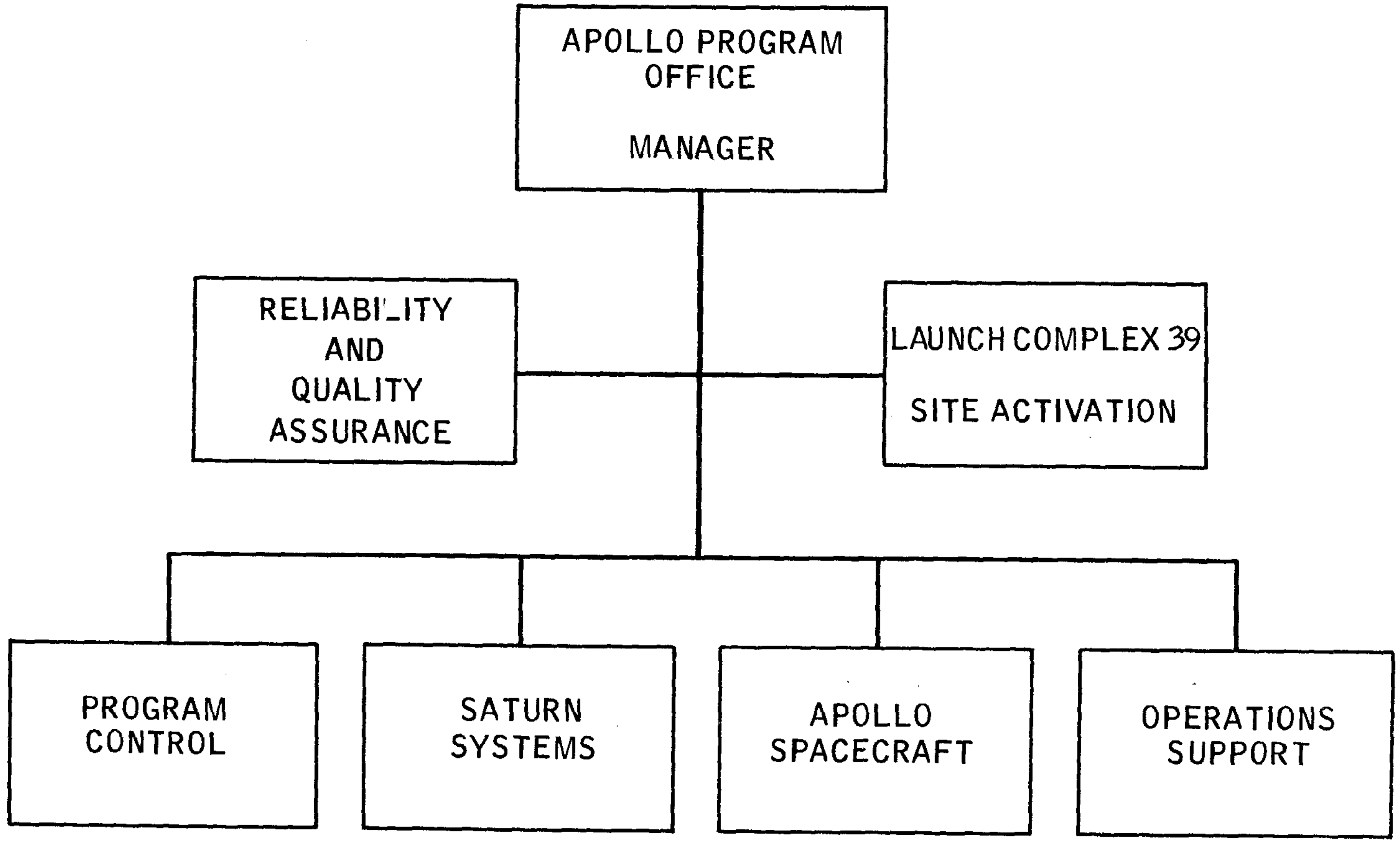

Figure E5-3.- Functional organization of the Apollo Program Office at KSC.

Apollo Program Directive No. 33A, issued in August 1968, defines in considerable detail the responsibilities of each of the three Centers in the Apollo Program. It is reproduced on the following pages in its entirety for reference.

OFFICE OF MANNED SPACE FLIGHT PROGRAM DIRECTIVE | M-D MA 1400.095 (Project) | DATE 5 AUG 1968

APOLLO PROGRAM DIRECTIVE NO. 33A

TO: DISTRIBUTION

~~FROM:~~ [signature] APOLLO PROGRAM DIRECTOR

SUBJECT: Center Responsibilities in the Apollo Program

OFFICE OF PRIME RESPONSIBILITY: MAP

I. PURPOSE

The purpose of this Directive is to assign responsibility and functions and define inter-Center relationships for the conduct of the Apollo Program.

II. SCOPE

This Directive assigns responsibilities and functions to MSF Centers for accomplishment of the Apollo Program in amplification of and in consonance with NMI 1142.1 Functions and Authority - Manned Spacecraft Center, NMI 1142.3 Functions and Authority - George C. Marshall Space Flight Center, and NMI 1142.2 Functions and Authority - John F. Kennedy Space Center.

III. RESPONSIBILITY

A. The Director of the Manned Spacecraft Center is responsible for design, development, fabrication, qualification, acceptance test and delivery of Apollo spacecraft; associated ground support equipment and assigned experiments; for the planning of all Apollo Missions; for the control of the flight phase of Apollo Missions including the development of ground equipment necessary for mission control and not provided by other centers in the execution of their missions; for the selection, training and assignment of flight crews; for the development of software as needed for spacecraft guidance, checkout, and mission control; for establishing prelaunch requirements for test, checkout and inspection of Apollo spacecraft; and for the planning and implementation of a lunar science program to support the Apollo Program.

B. The Director of the George C. Marshall Space Flight Center is responsible for the design, development, fabrication, qualification, acceptance test and delivery of the Saturn launch vehicles including engines, associated ground support equipment and assigned experiments; providing mission planning data from the standpoint of overall vehicle performance; providing launch vehicle data and software for launch vehicle guidance and checkout; for establishing prelaunch requirements for test, checkout and inspection of Saturn launch vehicles; and supporting launch and flight operations as requested by KSC and MSC.

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C. The Director of the John F. Kennedy Space Center is responsible for development and operation of launch and industrial facilities and associated ground support equipment required to support the Apollo Program and the assembly, test, inspection, checkout and launch of Apollo-Saturn space vehicles at KSC.

D. Center Directors will retain ultimate responsibility for Apollo Program functions delegated within the Center, and will supervise their performance. Significant changes in delegation of functions will be discussed with the Apollo Program Director prior to implementation.

IV. FUNCTIONS

A. Manned Spacecraft Center

The Manned Spacecraft Center is assigned the following functions for the Apollo Program:

1. Hardware

a. Providing for the detailed specifications, design, manufacture, checkout, test, reliability and quality, qualification, and acceptance of MSC developed hardware. This does not include the test and checkout functions accomplished at the launch site by KSC.

b. Developing and delivering to KSC spacecraft which has been qualified for flight along with associated software, data and support equipment.

c. Providing for the detailed specifications, design, development, fabrication, qualification, acceptance test and delivery of experiments flight hardware and associated specialized ground equipment for those experiments approved by the Manned Space Flight Experiments Board and assigned by the Apollo Program Director.

d. Providing logistic support planning and implementation at factory, test and launch sites for MSC developed hardware.

e. Controlling receipt and stowage of flight crew personal equipment at KSC which is scheduled for flight and providing to KSC a list of equipment which is considered flight crew personal equipment.

2. Configuration Control

a. Establishing and controlling configuration of spacecraft hardware, associated software and support equipment (designed or provided by MSC) at each stage of preparation or test in the factory, test or launch site, including approval of changes at KSC.

b. Providing and maintaining a list of acceptable items and materials that may enter the spacecraft for checkout and for flight.

3. Test and Checkout

a. Establishing and maintaining test and checkout requirements and test and checkout specifications and criteria for factory or test site acceptance and launch site preparation of MSC developed hardware (including Ground Support Equipment and software).

b. Providing test and checkout requirements and test and checkout specifications and criteria for launch site preparation of MSC developed hardware, software and Ground Support Equipment.

c. Reviewing factory, test site and launch site test requirements and test and checkout plans and procedures as necessary to assure that adequate testing is being accomplished without unnecessary overlap and duplication between testing conducted at different locations.

d. Providing written approval of KSC test and checkout plans in consonance with paragraphs IV.A.3b and IV.A.3c.

e. Providing Center approved factory or test site test and checkout procedures to KSC for use as a baseline in the development of similar procedures required at the launch site.

f. Reviewing at the option of MSC, the adequacy of KSC test procedures at the launch site.

g. Providing requirements and criteria to KSC for assuring flight readiness of experiments flight hardware, unless KSC and MSC on the basis of written agreement for a specific experiment make other arrangements for flight readiness determination.

h. Determining functional performance and flight readiness of flight hardware closed out at the factory or test site and not accessible for inspection or not included in test and checkout requirements for evaluation of functional performance at KSC.

i. Providing such technical assistance or data as may be required by KSC in preparation of hardware for flight.

j. Assuring that MSC personnel participating in KSC tests are responsive to KSC direction during conduct of the tests and attend pre-test briefings and participate in training exercises as required by KSC in accordance with responsibilities outlined herein.

k. Providing an assessment of flight readiness of the spacecraft and associated software at the Flight Readiness Review in accordance with Apollo Program Directives.

4. Reliability and Quality Assurance

a. Providing quality control requirements and inspection criteria for MSC developed hardware for use at the factory, test site and launch site.

b. Conducting audits to evaluate contractor factory and test site performance in accordance with MSC quality control requirements and inspection criteria for MSC developed hardware, and participating at the option of MSC in audits conducted by KSC at the launch site.

c. Determining corrective action and disposition of MSC developed hardware which fails, malfunctions or performs outside the performance limits contained in test and checkout specifications and criteria during checkout at KSC. This responsibility does not include routine trouble-shooting or maintenance of MSC developed ground support equipment operated by KSC.

5. Systems Engineering

Providing MSC technical representation on design and operations inter-Center panels or working groups as established by Apollo Program Directives.

6. Operations

a. Developing flight techniques for mission control and hardware and software for the Mission Control Center.

b. Developing mission objectives, plans and rules to support Apollo mission assignments.

c. Conducting flight operations.

d. Obtaining from KSC the operational requirements pertaining to checkout and launch which need to be incorporated into MSC designed hardware.

e. Planning jointly with the Department of Defense the provision of recovery support.

f. Providing input to and comment on KSC launch rules.

g. Identifying MSC operational support requirements according to approved procedures and evaluating support implementation of said requirements.

7. Flight Crew

    a. Providing trained flight crews and personal equipment for manned missions.

    b. Directing all astronaut activities except during the time they are participating in KSC flight hardware tests.

    c. Developing and operating flight crew simulators and training equipment at MSC and KSC.

8. Science

    a. Planning and implementation of a lunar science program to support Apollo, including site selection, lunar science operations, the Lunar Receiving Laboratory operation and lunar sample analysis.

9. Management

This section contains general management responsibilities for the conduct of the Apollo program at MSC as well as some specific management requirements which need to be highlighted.

General

a. Assuring that Apollo program requirements for manpower or for institutional support from other elements of MSC are properly conveyed to those elements and that Apollo program institutional support requirements are reflected in Center resource requirements plans, schedules, and budgets.

b. Assuring that Apollo program requirements for institutional support are met on an effective and timely basis.

c. Developing and operating Center facilities required for the Apollo Program.

d. Developing and implementing adequate security procedures.

e. Establishing detailed schedules (Levels 2, 3 and 4) for MSC hardware, software and associated equipment and operations activities consistent with the basic schedules (Level 1) approved by the Director, Apollo Program, and the Director, Mission Operations.

f. Providing contract authority for KSC control of spacecraft contractor's test and checkout activities at KSC through a supplemental contract under KSC administration.

Medical

Medical support for the Apollo program will be provided in accordance with NMI 8900.1. In addition, the following specific requirements will be met on the Apollo program.

a. Providing for the medical surveillance and support of the astronauts during all phases of the Apollo Program at any location including test and checkout operations.

b. Providing for the evaluation of medical data obtained during manned tests, to insure that the interpretation of such data regarding the acceptability of equipment performance is properly reflected in post flight mission reports.

c. Providing for the development and implementation of medical disaster plans associated with the test of Apollo hardware at MSC.

Safety

Safety activities in the Apollo program will be conducted in accordance with instructions provided by the Apollo Program Director and directives issued by the Manned Space Flight and NASA Safety Directors. In addition the following specific requirements will be met on the Apollo program.

a. Providing written approval of KSC criteria for determining hazardous operations at the launch site.

b. Reviewing and approving any KSC test and checkout procedure in which the flight crew participates.

B. George C. Marshall Space Flight Center

The George C. Marshall Space Flight Center is assigned the following functions for the Apollo Program.

1. Hardware

a. Providing for the detailed specifications, design, manufacture, checkout, test, reliability and quality, qualification and acceptance of MSFC developed hardware. This does not include the test and checkout functions accomplished at the launch site by KSC.

b. Developing and delivering to KSC launch vehicles which have been qualified for flight along with associated software, data and support equipment.

c. Providing for the detailed specifications, design, development, fabrication, qualification, acceptance test and delivery of experiments flight hardware and associated specialized ground equipment for those experiments approved by the Manned Space Flight Experiments Board and assigned by the Apollo Program Director.

d. Providing logistic support planning and implementation at factory, test and launch sites for MSFC controlled hardware.

2. Configuration Control

a. Establishing and controlling configuration of launch vehicle hardware, associated software and support equipment (designed or provided by MSFC) at each stage of preparation or test in the factory, test or launch site, including approval of changes at KSC.

b. Providing criteria to KSC for controlling tools, equipment and materials that enter and leave the launch vehicle stages and instrument unit during operations at KSC.

3. Test and Checkout

a. Establishing and maintaining test and checkout requirements and test and checkout specifications and criteria for factory or test site acceptance and launch site preparation of MSFC developed hardware (including Ground Support Equipment and software).

b. Providing test and checkout requirements and test and checkout specifications and criteria for launch site preparation of MSFC developed hardware, software and Ground Support Equipment.

c. Reviewing factory, test site and launch site test requirements and test and checkout plans and procedures as necessary to assure that adequate testing is being accomplished.

d. Providing written approval of KSC test and checkout plans in consonance with paragraphs IV.B.3b and IV.B.3c.

e. Providing Center approved factory or test site test and checkout procedures to KSC for use as a baseline in the development of similar procedures required at the launch site.

f. Reviewing at the option of MSFC, the adequacy of KSC test procedures at the launch site.

g. Providing requirements and criteria to KSC for assuring flight readiness of experiments flight hardware, unless KSC and MSFC on the basis of written agreement for a specific experiment make other arrangements for flight readiness determination.

h. Determining functional performance and flight readiness of flight hardware closed out at the factory or test site and not accessible for inspection or not included in test and checkout requirements for evaluation of functional performance at KSC.

i. Providing such technical assistance or data as may be required by KSC in preparation of hardware for flight.

j. Assuring that MSFC personnel participating in KSC tests are responsive to KSC direction during conduct of the tests and attend pre-test briefings and participate in training exercises as required by KSC in accordance with responsibilities outlined herein.

k. Providing an assessment of flight readiness of the launch vehicle and associated software at the Flight Readiness Review in accordance with Apollo Program Directives.

4. Reliability and Quality Assurance

a. Providing quality control requirements and inspection criteria for MSFC developed hardware for use at the factory, test site and launch site.

b. Conducting audits to evaluate contractor factory and test site performance in accordance with MSFC quality control requirements and inspection criteria for MSFC developed hardware, and participating at the option of MSFC in audits conducted by KSC at the launch site.

c. Determining corrective action and disposition of MSFC developed hardware which fails, malfunctions, or performs outside the performance limits contained in test and checkout specifications and criteria during checkout at KSC. This responsibility does not include routine trouble-shooting or maintenance of MSFC-developed ground support equipment operated by KSC.

5. Systems Engineering

a. Providing MSFC technical representation on design and operations inter-Center panels or working groups as established by Apollo Program Directives.

b. Providing the overall integrated space vehicle systems analysis and criteria for operational requirements and limitations for handling, checkout, launch and flight as required by MSFC, MSC and KSC.

c. Operating the Manned Space Flight Interface Documentation Repository.

6. Operations

a. Developing mission objectives and plans to support Apollo mission assignments.

b. Providing real time mission support as requested by MSC and KSC both on site and at Huntsville.

c. Providing input to and comment on KSC launch and MSC flight mission rules.

d. Obtaining from KSC the operational requirements pertaining to checkout and launch which need to be incorporated into MSFC designed hardware.

e. Identifying MSFC operational support requirements according to approved procedures and evaluating support implementation of said requirements.

7. Flight Crew

Providing instructions and material for training and familiarization of flight crews with the Saturn vehicle.

8. Science

None

9. Management

This section contains general management responsibilities for the conduct of the Apollo program at MSFC as well as some specific management requirements which need to be highlighted.

General

a. Assuring that Apollo program requirements for manpower or for institutional support from other elements of MSFC are properly conveyed to those elements and that Apollo program institutional support requirements are reflected in Center resource requirements plans, schedules, and budgets.

b. Assuring that Apollo program requirements for institutional support are met on an effective and timely basis.

c. Developing and operating Center facilities required for the Apollo Program.

d. Developing and implementing adequate security procedures.

e. Establishing detailed schedules (Levels 2, 3 and 4) for MSFC hardware, software, and associated equipment consistent with the basic schedules (Level 1) approved by the Apollo Program Director.

f. Providing liquid hydrogen management for MSFC and KSC.

g. Providing contract authority for KSC control of launch vehicle contractor's test and checkout activities at KSC through a supplemental contract under KSC administration.

Medical

Medical support for the Apollo program will be provided in accordance with NMI 8900.1. In addition, the following specific requirement will be met on the Apollo program.

a. Providing for the development and implementation of medical disaster plans associated with the test of Saturn hardware at MSFC.

Safety

Safety activities in the Apollo program will be conducted in accordance with instruction provided by the Apollo Program Director and directives issued by the Manned Space Flight and NASA Safety Directors. In addition the following specific requirement will be met on the Apollo program.

a. Providing written approval on KSC criteria for determining hazardous operations at the launch site.

C. John F. Kennedy Space Center

The John F. Kennedy Space Center is assigned the following functions for the Apollo Program.

1. Hardware

a. Providing for detailed specifications, design, manufacture, checkout, test, reliability and quality, qualification and acceptance of KSC developed hardware.

b. Developing and delivering qualified ground support equipment associated with launch facilities and not provided by MSC or MSFC.

c. Developing and operating ground communications, computation, and instrumentation systems and equipment for the conduct of launch operations.

d. Taking measures to protect flight hardware and associated Ground Support Equipment from contamination, corrosion or damage which may result from environment, housekeeping, procedure or human error and reporting incidents to MSC and MSFC as appropriate.

e. Providing logistics support planning and implementation at the factory test or at KSC for KSC developed hardware.

2. Configuration Control

a. Establishing and controlling configuration of KSC developed launch facilities and ground support equipment at each stage of preparation or test at the factory, test site or at KSC.

b. Maintaining configuration control of MSC and MSFC developed hardware and software after delivery to KSC in accordance with the configuration requirements established by MSC and MSFC. Assuring that prior approval is secured from MSC and MSFC before any changes in configuration are made in spacecraft, launch vehicle, or associated GSE furnished by MSC or MSFC.

c. Securing, after the flight readiness test, the prior approval of MSC or MSFC for the replacement of failed parts.

d. Controlling everything that enters and leaves the spacecraft during checkout at KSC in accordance with the MSC list of acceptable items and materials that may be taken into the spacecraft for checkout and for flight.

e. Controlling tools, equipment and materials that enter and leave the launch vehicle stages and instrument unit during operations at KSC in accordance with criteria provided by MSFC.

3. Logistics Management

a. Provide total logistics support planning and management for all KSC equipment. Plan for the utilization at KSC of equipment provided by other design cognizant centers, using the inter-center coordinated support planning provided by those centers.

b. Provide logistics products and services to meet the valid intent of NHB 7500.1 for KSC designed equipment. Utilize logistics products and services provided by other centers to support equipment under their design cognizance, unless stipulated otherwise in inter-center logistics agreements.

c. Receive, store, issue and dispose of spare parts for all Apollo Program equipment operated at KSC in accordance with inter-center coordinated plans and directions from the design cognizant centers.

d. Provide reports of logistics requirements, status and spares consumption as required.

e. Establish, implement and control a logistics discrepancy reporting system.

4. Test and Checkout

a. Conducting the assembly, checkout, and launch of flight hardware for Apollo missions and assembly, checkout and operation of required ground support equipment.

b. Providing control of all personnel participating in test and checkout activities, including representatives from MSC and MSFC, and assuring that personnel attend pre-test briefings and participate in training exercises as necessary to assure personnel safety and proper conduct of the tests.

c. Providing requirements, specifications and criteria, and procedures for test and checkout of KSC developed support equipment whose performance must be verified for each launch.

d. Providing test and checkout plans in accordance with MSC and MSFC test and checkout requirements plus any additional KSC test requirements necessary to verify launch facility, Manned Space Flight Network and launch crew readiness or to satisfy range and safety requirements.

e. Securing MSC and MSFC written approval on test and checkout plans and changes thereto before the plans are approved or implemented.

f. Developing and providing to MSC or MSFC test and checkout procedures adapted to the KSC environment using as a baseline the development center approved factory test and checkout procedures.

g. Making final determination that test and checkout procedures are adequate, safe and in accordance with MSC and MSFC test and checkout requirements and test and checkout specifications and criteria.

h. Obtaining approval on deviations and waivers from MSC and MSFC concerning test and checkout requirements, test and checkout specifications and criteria and inspection criteria when unable to meet requirements.

i. Determining functional performance and flight readiness of flight hardware and software in accordance with test and checkout requirements and test and checkout specifications and criteria provided by MSC and MSFC except for that which is closed out at the factory and not accessible for inspection or not included in test and checkout requirements for evaluation of functional performance at KSC.

j. Determining flight readiness of equipment associated with inflight experiments in accordance with MSC or MSFC (as appropriate) specifications and criteria unless specifically excluded by written agreement with MSC or MSFC.

k. Controlling receipt and storage, and assuring flight readiness of all Government Furnished Equipment, other than flight crew personal equipment, which is scheduled for flight and which is not processed to KSC through a contractor responsible to KSC.

l. Providing routine trouble shooting and maintenance for MSC and MSFC developed equipment in accordance with MSC and MSFC requirements, specifications and criteria.

m. Providing an assessment of the flight readiness of the launch complex, flight hardware and software at the Flight Readiness Review in accordance with Apollo Program Directives.

5. Reliability and Quality Assurance

a. Providing quality control requirements and inspection criteria for KSC developed hardware for use at the factory, test site and KSC.

b. Conducting audits to evaluate contractor factory and test site performance in accordance with KSC quality control requirements and inspection criteria for KSC developed hardware.

c. Determining corrective action and disposition of KSC developed hardware which fails, malfunctions, or performs outside the performance limits contained in test and checkout specifications and criteria during checkout at KSC.

d. Generating approval from the appropriate development center (MSC or MSFC) to disassemble or open any flight hardware closed out at a factory or test site.

e. Securing MSC and MSFC written approval of quality control plans insofar as development center responsibilities are concerned before the plans are approved or implemented.

f. Conducting quality control inspections and audits of contractor activities at KSC and inviting MSC and MSFC participation as applicable.

g. Obtaining approval from the appropriate development center (MSC or MSFC) to disassemble or open any flight hardware closed out at a factory or test site.

h. Advising MSC or MSFC of any problem arising during prelaunch preparation concerning flight worthiness of flight hardware.

i. Conducting failure analysis as required by MSC and MSFC.

j. Participating in MSC and MSFC flight hardware acceptance reviews and providing recommendations to MSC or MSFC and the Apollo Program Director, concerning the acceptance of the hardware for shipment to KSC.

6. Systems Engineering

Providing KSC representation on design and operations inter-Center panels or working groups as established by Apollo Program Directives.

7. Operations

a. Identifying KSC operational support requirements according to approved procedures and evaluating implementation of support planning.

b. Providing data to MSC and MSFC in accordance with approved Program Support Requirements Documents.

c. Conducting launch operations.

d. Developing launch plans and rules.

8. Flight Crew

Coordinating and directing astronaut activities during the time they are actively participating in KSC tests of flight hardware except that the flight crew may take any action necessary for their safety.

Science

None

10. Management

This section contains general management responsibilities for the conduct of the Apollo program at KSC as well as some specific management requirements which need to be highlighted.

General

a. Assuring that Apollo program requirements for manpower or for institutional support from other elements of KSC are properly conveyed to those elements and that Apollo program institutional support requirements are reflected in Center resource requirements plans, schedules, and budgets.

b. Assuring that Apollo program requirements for institutional support are met on an effective and timely basis.

c. Providing control of all activities of Apollo contractors at KSC other than those directly associated with astronaut training.

d. Developing and operating Center facilities required for the Apollo Program.

e. Developing and implementing adequate security procedures.

f. Establishing detailed schedules (Levels 2, 3 and 4) for KSC hardware, software and associated equipment consistent with the basic schedules (Level 1) approved by the Director, Apollo Program and the Director, Mission Operations.

Medical

Medical support for the Apollo program will be provided in accordance with NMI 8900.1. In addition, the following specific requirement will be met on the Apollo program.

a. Providing for the development and implementation of medical disaster plans associated with the assembly, checkout and prelaunch operations of Apollo flight hardware at KSC.

Safety

Safety activities in the Apollo program will be conducted in accordance with instructions provided by the Apollo Program Director and directives issued by the Manned Space Flight and NASA Safety Directors. In addition the following specific requirements will be met on the Apollo program.

a. Performing as the NASA single point of responsibility for safety in the Merritt Island and Cape Kennedy area and for NASA range safety inputs to the Eastern Test Range.

b. Developing criteria for determining hazardous operations at the launch site and securing written approval of MSC and MSFC.

V. PRECEDENCE

This Directive takes precedence over any inter-Center agreements on Apollo program responsibilities.

VI. CONCURRENCE

This Program Directive has been reviewed and concurred in by the Associate Administrator for Manned Space Flight and the Associate Administrator for Organization and Management. Any proposed substantive changes in the responsibilities defined in this document will be submitted for review and concurrence in the same manner.

PROGRAM MANAGEMENT CONTINUITY

The Panel considered the question of continuity of experience in certain key positions at MSC, KSC, NR-Downey, and Beech, and found that it has been good.

At MSC, three different men have held the Subsystem Manager position for the cryogenic gas storage subsystem since November 1963. The first held the position for nearly 3 years during the later design phases and through most of the oxygen tank development period. The second Subsystem Manager was in the position from 1966 through 1968 and was then succeeded by the present incumbent, who had been his assistant.

In the MSC ASPO, there have been five Program Managers, two during the design and development of the oxygen tank. Additional continuity in this position was provided from 1961 through 1966, by the fact that the first Program Manager became the Deputy Program Manager in 1962 and served in that position, under two successive Program Managers, through 1965. In 1967, when the Program Manager next changed, the position was taken by the then Deputy Director of the Center, who had been associated with the Program from that position. The present Program Manager, who took over last year, had been an astronaut with detailed familiarity with the manned space flight program since 1962.

At KSC, the persons with principal responsibility for the test, checkout, and launch of all Apollo spacecraft are the Director of Launch Operations and, reporting to him, the Director of Spacecraft Operations. Continuity in these positions has been good. The present Director of Launch Operations was the Deputy Director for the prior 2 years, approximately. Before that he had been the head of the MSC Resident Apollo Spacecraft Office at KSC. The present incumbent of the Spacecraft Operations position has occupied that position for 5 years. Prior to that time he served as the Assistant Manager for Gemini, MSC Florida Operations.

At North American Rockwell the position with direct responsibility for overseeing design and manufacture of the cryogenic gas storage system (CGSS) by the subcontractor, Beech, is the Manager, Fuel Cells and Cryogenic Systems (fig. E4-10). The present incumbent of that position has held it since 1962 and has been NR-Subsystem Manager for the Apollo CGSS over that entire period. The present Apollo Program Manager at NR succeeded to that position last year when the former Program Manager was appointed NASA Associate Administrator for Manned Space Flight. Prior to his promotion, the present Program Manager had been the Assistant CSM Program Manager for about 4 years.

At Beech-Boulder Division, the same men have occupied one or another of the key positions in the CGSS contract to NR over the life of the contract. There has been turnover in manufacturing personnel at the technician and trades levels but the principal managers and supervisors have not changed. It is noteworthy that when members of the Apollo 13 Review Board visited Beech for a demonstration of the assembly of an Apollo oxygen tank, the technician who performed the assembly demonstration was the same man who had assembled Apollo 13 tank no. 2 in 1966.

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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

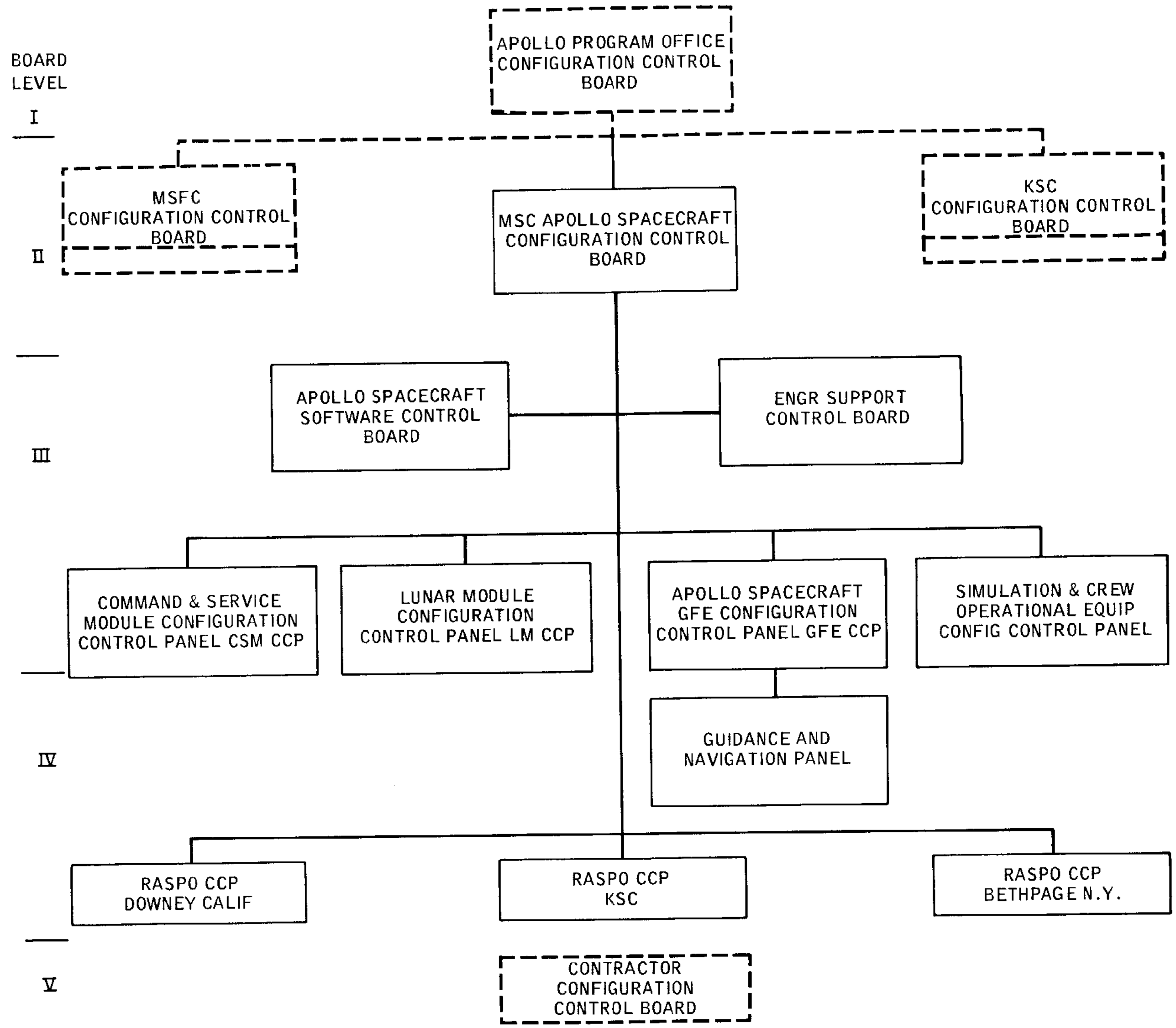

Figure E6-1.- Configuration Control Boards - Apollo Spacecraft Program.

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.

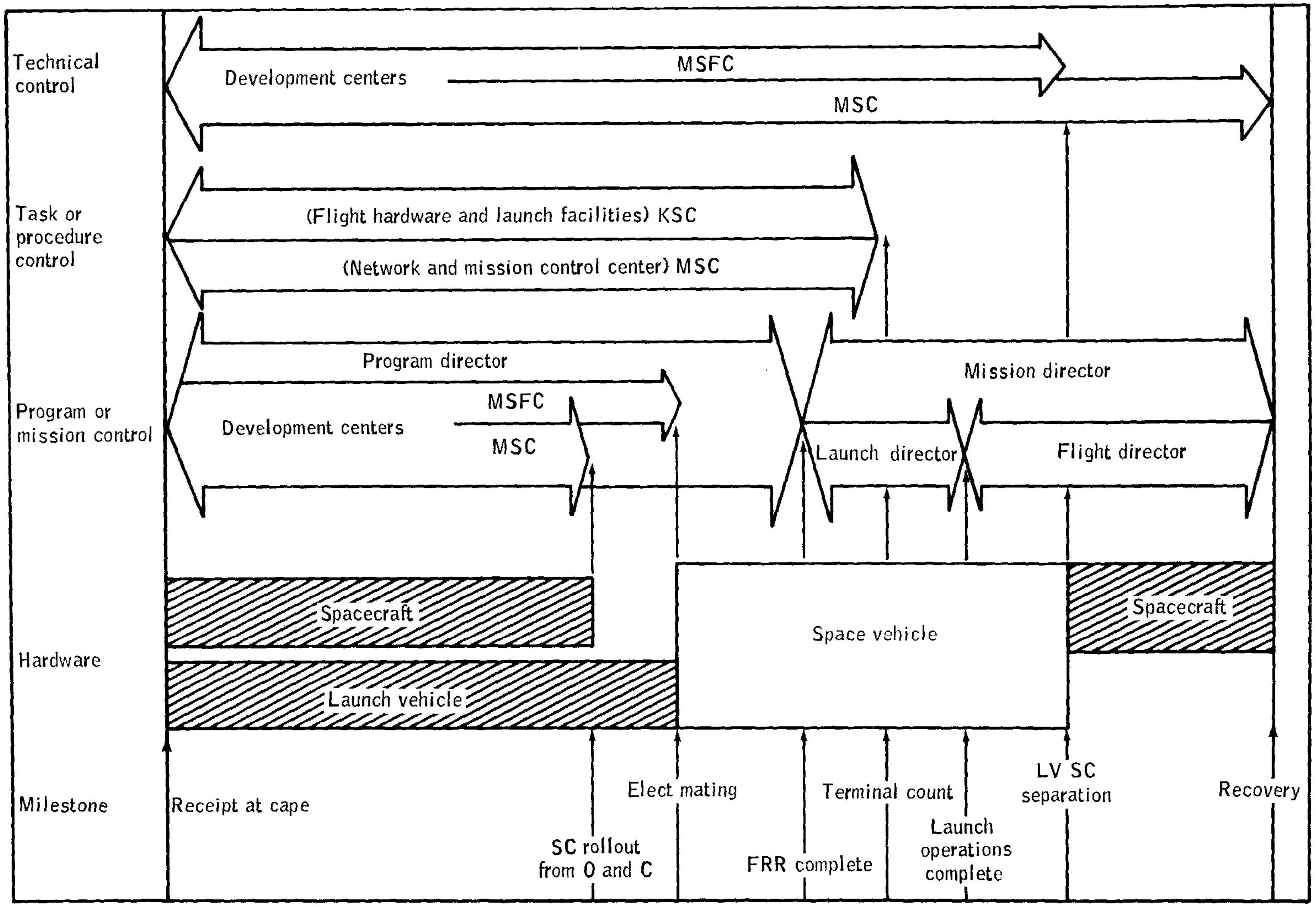

Figure E6-2.- Mission responsibility relationships.

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.

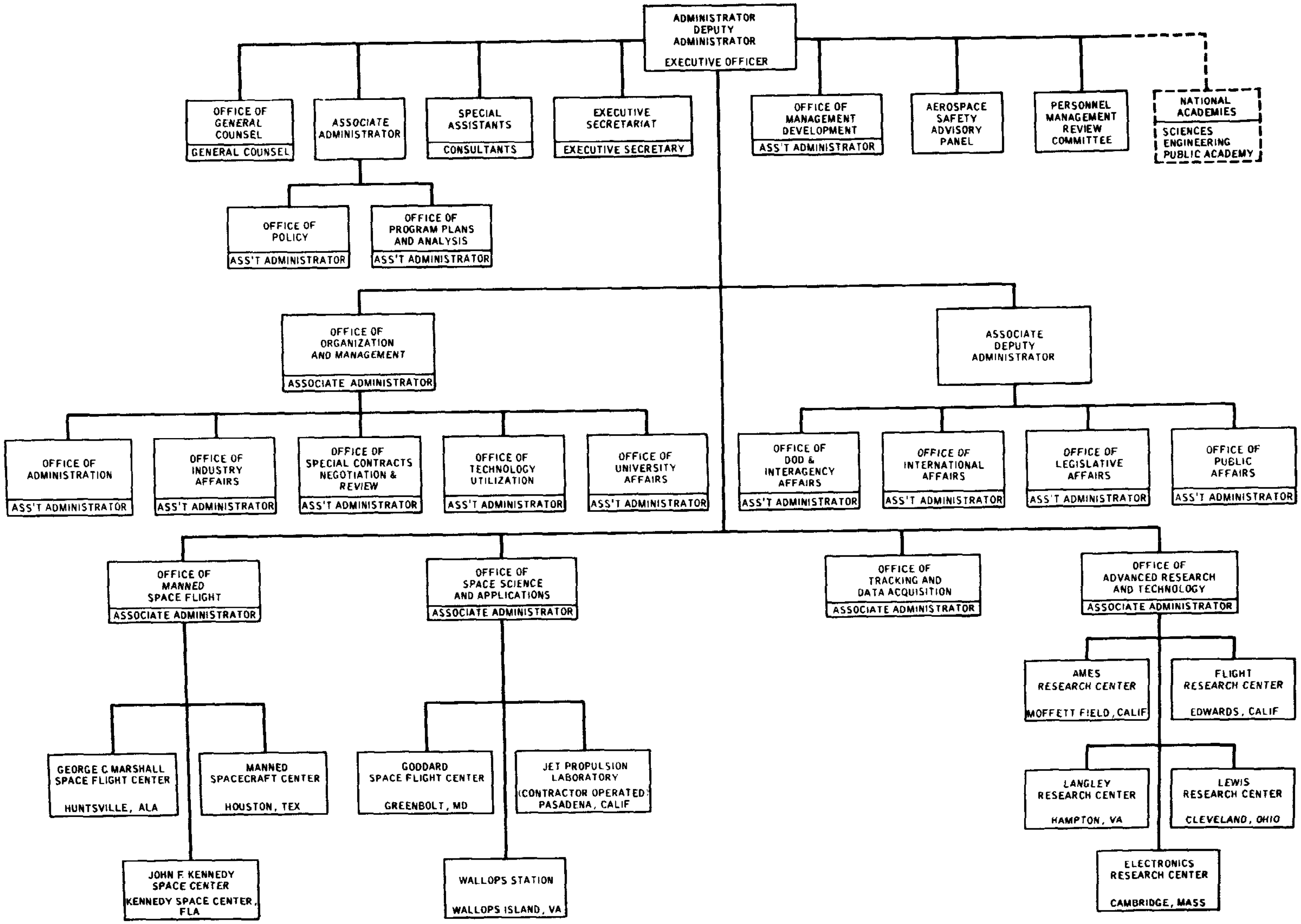

Figure E9-1.- National Aeronautics and Space Administration.

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.

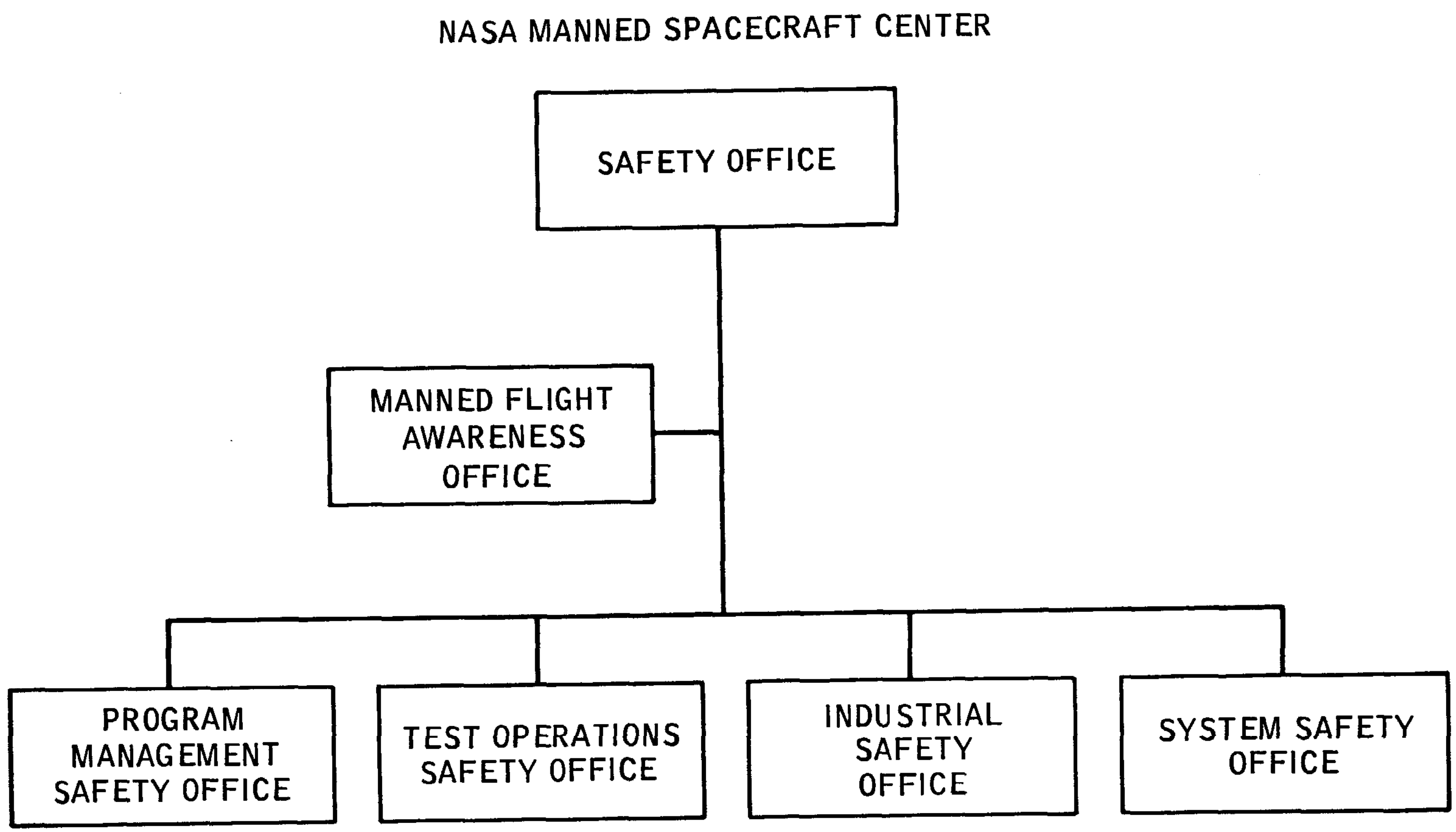

Figure E9-2.- MSC Safety Office organization.

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

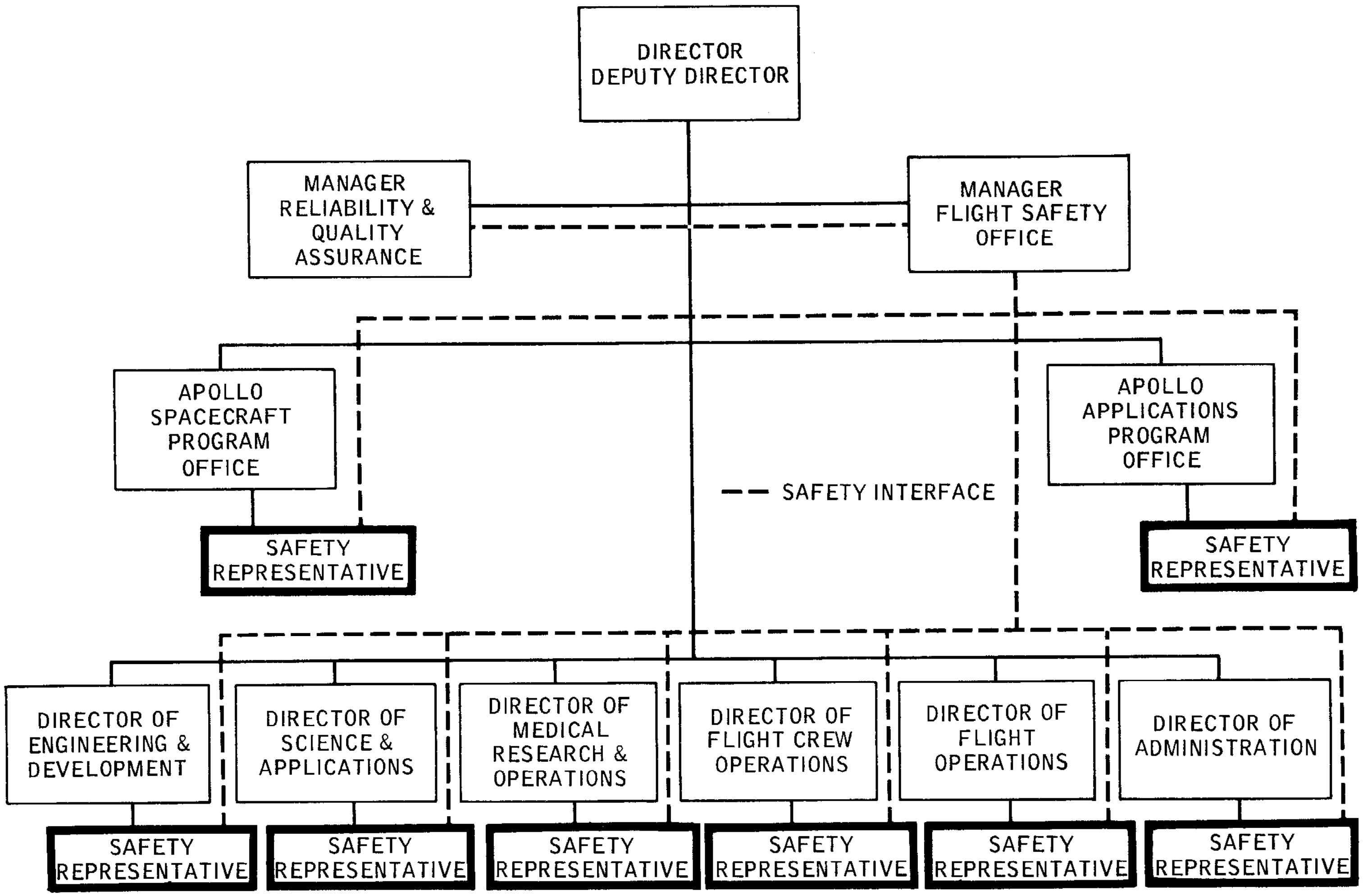

Figure E9-3.- Safety Functional Office, NASA Manned Spacecraft Center.

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.

(f) Establishes the physiological limits to which man can be subjected.

(g) Reviews plans and changes for construction of test facilities involving humans.

(h) Has responsibility for biological safety during Lunar Receiving Laboratory operations.

The Safety Office also maintains a safety interface between NASA Headquarters, MSC, other centers, and other Government agencies as shown in figure E9-4. The areas of safety coordination with these organizations are described as follows. In the event problems arise at these interfaces, interagency panels will be convened for problem resolution.

MSC/KSC interface in eight areas that are safety oriented or related:

1. Test operations at KSC.

2. Flight hardware management.

3. Flightcrew activities at KSC.

4. Configuration control.

5. Quality control and inspection at KSC.

6. Safety at KSC.

7. Experiment management.

8. Launch and flight operations.

Any problems which arise are resolved through the formally organized intercenter panels.

MSC/DOD Safety Regulations are primarily at the Air Force Eastern Test Range Facility. DOD provides the following functions:

1. Safety-related base support as required:

   (a) Fire protection and control

   (b) Explosive ordnance disposal

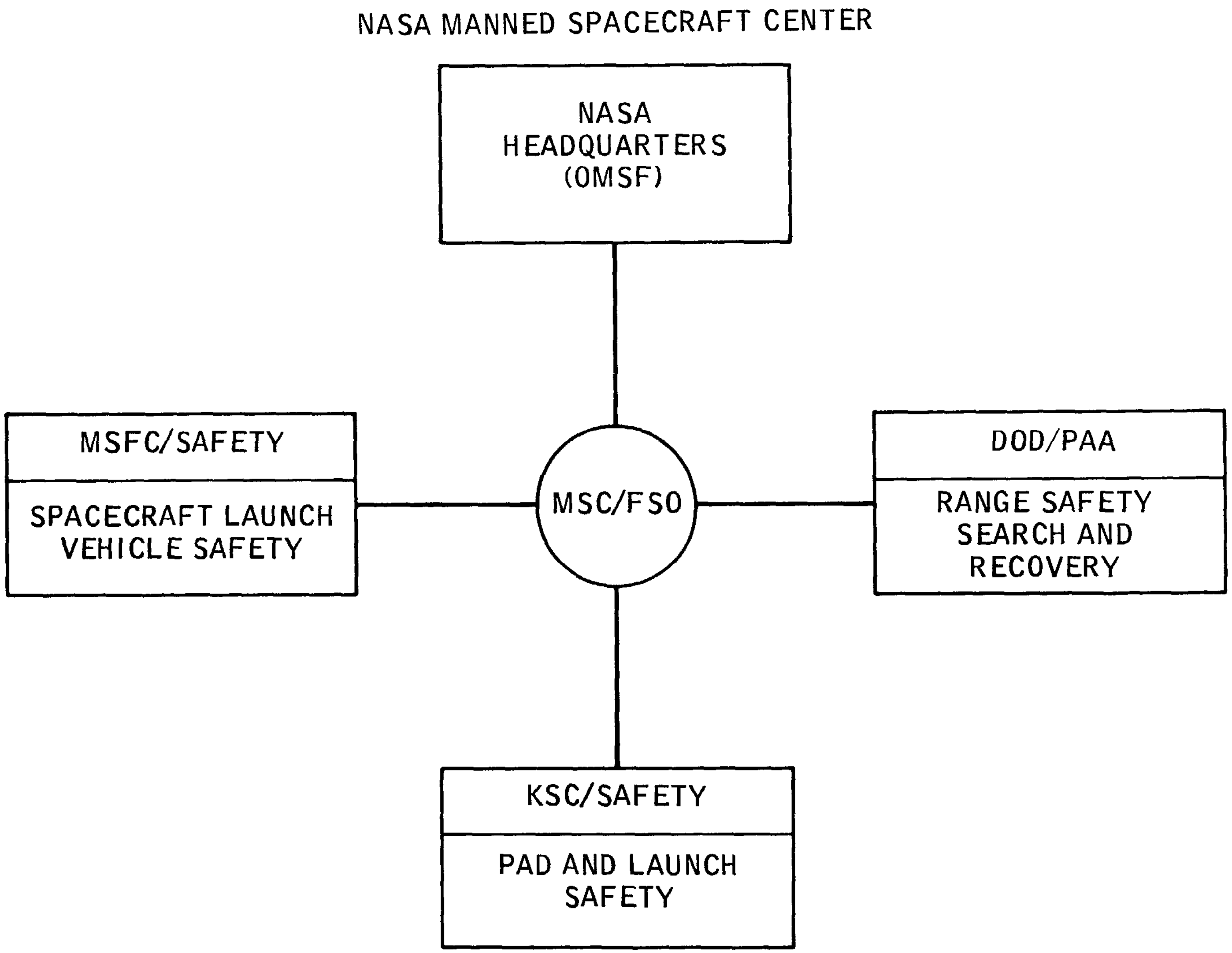

Figure E9-4.- MSC interrelationship with other organizations safety offices.

(c) Bioenvironmental engineering

(d) Security

2. Missile ground safety as required.

3. Range safety.

4. Search and sea recovery.

John F. Kennedy Space Center

The Kennedy Space Center takes the test and checkout requirements and test and checkout specifications and criteria documents prepared by the development centers and develops plans and procedures for the handling and launch of spacecraft. To accomplish this responsibility, KSC prepares and coordinates Test and Checkout Plans and implementing Test and Checkout Procedures.

The KSC Safety Office.- This office plans and manages an integrated hazard-assessment and risk-reduction program for all activities at KSC and for all NASA activities at both Cape Kennedy Air Force Station (CKAFS), Florida, and Vandenburg Air Force Base (VAFB), California. This program includes:

1. Handling, storing, and transporting hazardous items such as missile propellants, ordnance, high-pressure gases, toxic fluids, and radioactive devices.

2. Insuring safety requirements are included in all contracts initiated or administered by KSC and that contractor performance is periodically evaluated.

3. Performing engineering system safety studies to assure inclusion of safety requirements in engineering design of space vehicle test and checkout (launch complex and ground support equipment/facilities and operations).

4. Insuring that safety controls and required support are in effect during performance of all operations.

5. Approving siting, construction, and modification plans for safety aspects.

The office conducts safety surveillance while selected operations are actually in progress, with authority to halt activities under specified circumstances.

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, the KSC Safety Office reviews and approves these procedures to assure that operations are compatible with KSC safety criteria and use appropriate safety personnel, techniques, and equipment.

Prior to publication of a technical procedure involving hazardous operations to (a) authorize work, (b) provide engineering instructions, and (c) establish methods of work control, the KSC Safety Office reviews and approves the procedure to assure that operations are compatible with KSC safety criteria and use appropriate safety personnel, techniques, and equipment.

During selected operations that involve hazardous sequences, the Safety Office has representatives on site. In the case of major integrated tests, i.e., CDDT, the number of representatives can be as high as 12, with three people on station in the Launch Control Center firing room and the remainder at various positions on the launch pad. The safety representative insures that safety requirements are implemented, approves or disapproves on-the-spot changes to Category I procedures made either by Procedure Change Request (PCR) or Deviation Sheets and assists the test supervisor in obtaining resolution on matters that have safety overtones.

North American Rockwell Corporation - Space Division

The NR System Safety Plan for the Apollo CSM program is the implementing document for the program required by MSC specification under the basic CSM contract.

The objective of the system is the elimination or control of risks to personnel and equipment throughout the manufacture, checkout, and flight missions of the Apollo CSM. To achieve this objective the CSM system safety program has an organization as shown in figure E9-5. The CSM System Safety Office reports directly to the CSM General Manager and is headed by the Assistant to the General Manager for CSM System Safety. The Assistant to the General Manager for CSM System Safety acts for the General Manager in the conduct of activities relating to all facets of safety for the CSM programs, and is a permanent member of the Space Division Safety Committee. He directs and monitors program activities necessary to assure an effective system safety program. He is responsible for preparation and compatibility of the CSM system safety programs at all sites with the exception of Launch Operations at KSC.

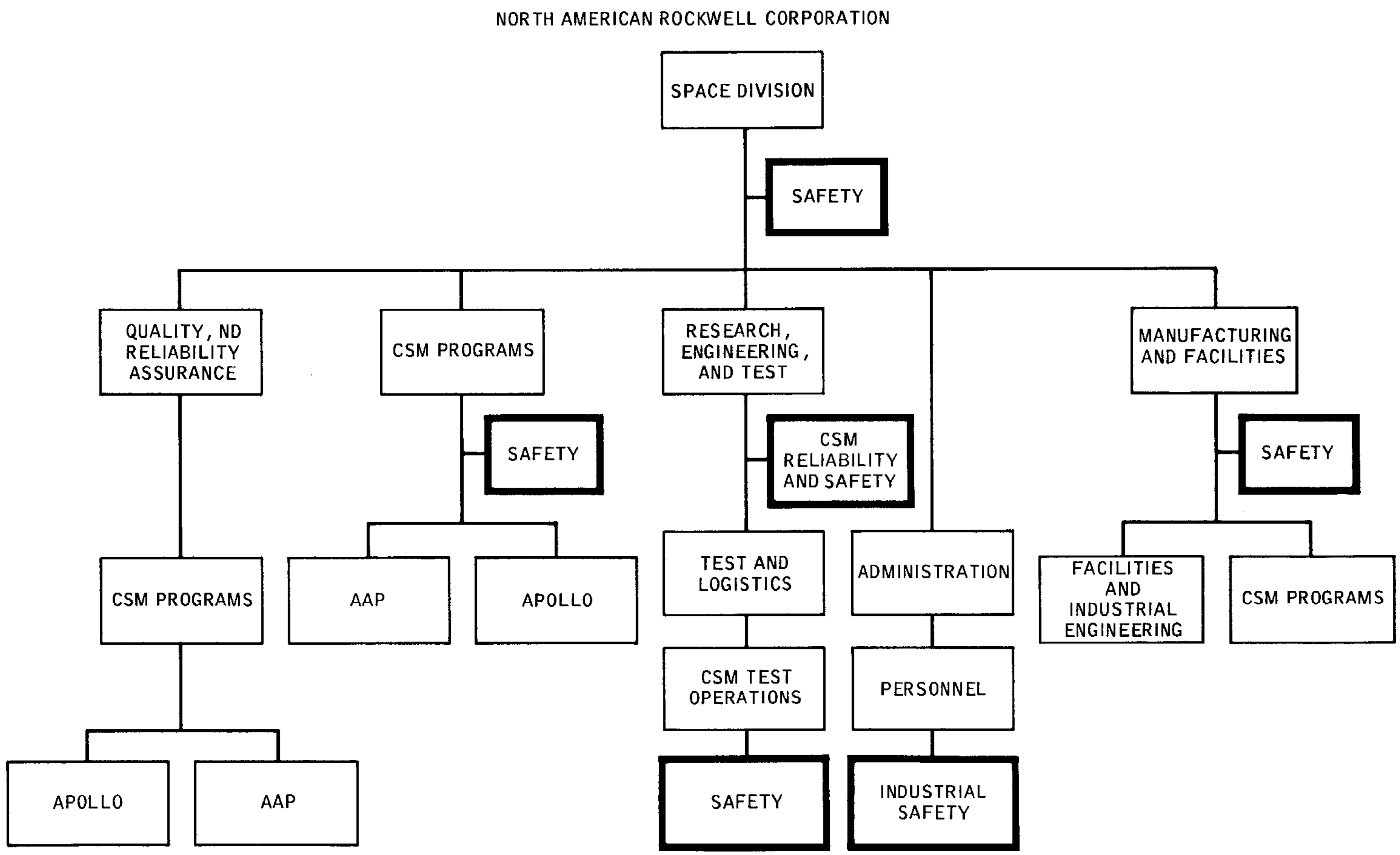

Figure E9-5.- Apollo CSM System Safety Program organization.

Specific responsibilities of the NR CSM Safety Office include:

1. Develop and direct the system safety program for the CSM programs.

2. Participate in Customer Acceptance Readiness Reviews (CARR's) and Flight Readiness Reviews (FRR's) and assess problems submitted for flightcrew safety impact.

3. Supervise the three CSM functional departments relative to system safety and interface with other agencies and divisions of NR concerning CSM safety.

4. Participate as a member of the NR Change Control Board (CCB) to review proposed changes and assure changes do not jeopardize ground and flightcrew safety.

5. Maintain status report system on all safety problems and design changes affecting safety.

The Engineering Division System Safety Office:

1. Reviews and evaluates safety effect of all Engineering Design Change (EDC) packages.

2. Reviews and assesses engineering analyses such as FMEA's, SPF's, and similar documents for identified hazards which jeopardize crew safety. Evaluate their corrective action and disposition.

3. Participates in postflight evaluations when requested by MSC for evaluation of crew safety problems.

The Manufacturing Division System Safety Office:

1. Provides safety checklists to aid manufacturing personnel in preparing documents and conducting safety surveys.

2. Assures that CSM manufacturing test, handling, and transport procedures and work documents contain appropriate system safety provisions.

3. Assures that operations defined as safety-critical are adequately planned and monitored.

The Test Operations System Safety Office is responsible for protection of the operational integrity of the CSM during checkout at Downey and testing at field sites. This office:

1. Generates system safety checklists for preparing Test Operations and conducting safety surveys.

2. Reviews all test, checkout, and operations procedures for adequate system safety requirements.

3. Reviews all safety-critical operations to assure adequacy of test set-up, documentation, and personnel qualification. Assures that adequate emergency plans and procedures are established and in use for these safety-critical operations.

4. Coordinates crew safety provisions and requirements and, when appropriate, recommends corrective action for identified hazards associated with crew procedures.

The Safety Plan appears to be operating satisfactorily according to the most recent MSC audit. The multiple safety offices and fragmented responsibilities warrant a critical review aimed at evaluating the expected effectiveness of a more centrally managed program.

The Reliability and Quality Assurance function, as shown in figure E9-5, has a functional responsibility to the corporate quality office and a program management responsibility to the CSM Program Manager. They are responsible for monitoring the manufacturing orders for proper R&QA callouts, verification inspection callouts, planned inspection callouts, and proper implementation of R&QA requirements in the planning operation. They also compile the System Summary Acceptance Documents (SSAD's) for Customer Acceptance Readiness Reviews (CARR's) and Flight Readiness Reviews (FRR's). They conduct quality inspections on manufacturing processes and testing operations and participate in design reviews. They also verify material usage and make and dispose of failed hardware.

The reliability function monitors design specifications and prepares failure effects and criticality analyses. They develop and supervise maintainability analyses, perform failure reporting analyses and recommend corrective action, support end-item reviews, perform problem investigations, and support the problem items.

Beech Aircraft Corporation

The overall organization of the Beech Aircraft Corporation, Boulder Division, is shown in figure E4-11, and a functional breakdown of the office of the Apollo Program is shown in figure E4-12. The Beech Quality Control Plan establishes the detailed methods and procedures for accomplishing the positive quality control required by NASA of its contractors and subcontractors in the Apollo Program. The Beech plan does comply with the NASA requirements of NPC-200-2, "Quality Program Provisions for Space Systems Contractors" (ref. 11), and is applicable to the material, parts, components, subassemblies, installations, and system and subsystems purchased, tested, and manufactured for the Apollo supercritical gas storage system.

The system operates to assure maintenance of the basic approved configuration baseline by reviewing and documenting materials, processes, vendor-provided equipment, testing procedures, and manufacturing operations.

The Beech Reliability Program Plan provides for management and operation of the reliability system. It provides for the monitoring and reporting of all tests, and maintenance of a complete record of action on discrepancies and failures; and participates in corrective action and research required for Failure Mode Effects Analysis (FMEA) analyses, logic diagrams, math models, and reliability predictions and apportionments. Documentation of these efforts are furnished to the NR and NASA to fulfill contract requirements. The Beech Aircraft reliability and quality assurance organization and operation appear to be adequate and in compliance with contract and NPC-200-2 requirements. Manufacturing procedures and process control were surveyed and found in good condition and documentation such as the FMEA's was examined and found to be satisfactory.

SAFETY AND R&QA AUDITS

Regular audits of the Safety and R&QA functional areas are made of the field centers by NASA Headquarters teams. The Centers, in turn, make similar audits of their prime contractors. These contractors conduct audits and survey visits with their subcontractors and suppliers. In addition, the NASA Aerospace Safety Advisory Panel has reviewed certain aspects of the manned space flight safety program. These reports are included in the Apollo 13 Review Board files.

Consideration of these audits and reviews by the Management Panel showed no significant items relative to the Apollo 13 accident. The general functioning of the overall Safety and R&QA programs was found to be consistent with good practices.

MSC SAFETY/R&QA PARTICIPATION

The MSC Safety Office is responsible for implementing safety policies and assuring safety in design, development, and operation of spacecraft. The R&QA function is responsible for assuring that spacecraft and supporting systems are designed and built to perform in the environment for which they are built. The two functions, Safety/R&QA, are mutually dependent, have many common information and data requirements, and have many review and monitoring functions that support them both.

Safety/R&QA are closely involved in the entire design, development, test, and flight phase of all spacecraft components, systems, and subsystems. This includes participation in formal reviews such as the Preliminary Design Reviews (PDR), Critical Design Reviews (CDR), First Article Configuration Inspection (FACI), and Customer Acceptance Readiness Reviews (CARR) conducted by the Program Office. Safety/R&QA also participates in Design Certification Reviews (DCR) and Flight Readiness Reviews (FRR).

These offices implement general policy and establish specific programs for contractors. They then monitor these programs throughout the contract period to assure safety and quality of performance by the contractor.

This review considered some of the activities of these two offices from the CARR through the post-touchdown phase of the command and service module of Apollo 13.

CARR's are held in two phases at present: Phase I prior to the initiation of subsystem testing and Phase III prior to shipping the assembled vehicle. MSC R&QA reviewed documentation for Phase III CARR for CSM 109 with the following specific results.

Phase III CARR for CSM 109

1. No hardware will exceed its allowable operational storage limits during KSC operation and flight.

2. No known parts problems exist that will constrain shipment of CSM 109.

3. There are 854 Certification Test Requirements (CTR's) for equipment applicable to CSM 109. Testing is incomplete for six and certification will not be complete at time of delivery. This status is significantly better than previous CSM's, however, and shows an improving trend.

4. An improving trend in spacecraft quality was shown by a review of NR-Downey discrepancy reports on CSM 109.

5. Verification of nonmetallic materials has been accomplished and establishes that all exposed nonmetallic materials have been identified and approved or deviations written and accepted.

6. All known single-point failures applicable to CSM 109 have been reviewed and are acceptable.

A comparison of data shown in the R&QA review for CSM 109 and previous CSM spacecraft shows that CSM 109 has shown substantial improvement in most R&QA and safety categories and no decrement in safety in any area.

FRR R&QA Summary

The next formal review was the Apollo 13 Flight Readiness Review (FRR).

1. All limited-life items adequate to support flight.

2. No known electrical, electronic, or electromechanical problems exist that would constrain launch.

3. No Certification Test Requirements constrain flight, since all have been approved except one which will be certified by analysis prior to flight.

4. All known single-point failures have been reviewed and are considered acceptable.

5. The overall quality of CSM 109 shows a favorable trend relative to previous spacecraft.

The Flight Safety assessment at the FRR was:

6. The system safety assessment of planned mission flight activities and spacecraft functions disclosed no safety concerns that would constrain the Apollo 13 flight scheduled for launch on April 11, 1970.

7. Four changes from previous missions have been made which reduced flight risks.

8. The risks unique to Apollo 13 involve: (a) programming S-IVB stage for lunar impact during translunar coast; (b) performing lunar descent orbit insertion with CSM/LM docked; (c) operating power drill on

lunar surface; and (d) performing PLSS communication degradation test during lunar surface EVA. These risks are not of constraining magnitude.

Weekly Safety/R&QA Report

In addition to the formal CARR, FRR, and other reviews, information is furnished to the Apollo Program Office and the Director, MSC, on a weekly basis of the activity of Safety and R&QA relative to particular spacecraft through the Weekly Activity Reports. Abbreviated mention of some items from this Weekly Report from January 1970 to April 10, 1970, concerning the Apollo 13 and CSM 109 follows.

January 8-15, 1970.- Thirteen open certification items for Apollo 13 were reported. Pacing items are four lunar camera items scheduled to be closed in February.

January 15-22, 1970.- CSM 109 FRR data review generated 10 R&QA Review Item Dispositions (RID's). CSM 109 FRR subsystem working session was conducted at KSC on January 15-16. FRR RID's were generated and submitted for preboard action on January 25. Readiness statements were prepared for CSM 109.

January 22-28, 1970.- An assessment of CSM 104 through 109 failures at KSC was conducted. Detailed assessment will be made to determine reasons failures were not discovered at NR before shipment.

Safety Office briefed Astronaut Conrad on proposed procedure change for Mode 4 abort. Conrad will review with other astronauts, including Apollo 13 Commander.

January 30-February 4, 1970.- Ground support equipment (GSE) at KSC supporting CSM 109 is defective and may provide a countdown demonstration and countdown constraint unless the situation is remedied. NR is studying the problem. The Apollo 13 Safety Assessment Study of Mission Phases from translunar injection through CSM descent orbit injection has been completed and will be distributed by February 4, 1970. The biweekly meeting of MSC Safety/Boeing System Safety on Apollo mission concerns was held January 30. Seventeen Apollo 13 safety concerns were reviewed. Eight of the seventeen were closed.

February 12-18, 1970.- R&QA and Apollo Test Division met to discuss anomaly reporting effort. The discussion disclosed no duplication of effort and agreement was reached that the Apollo Mission Anomaly Test would be the guide for anomaly investigations. As of this date, only one GSE problem is open. It is expected to be resolved by the CDDT.

February 19-26, 1970.- The Safety Offices Assessment Report for Apollo 13 has been prepared. There are no constraining items in the report.

February 26-March 5, 1970.- The Apollo 13 R&QA Flight Readiness Assessment Report was completed February 26, 1970. R&QA agrees with the data and conclusions drawn. Of the five items listed as requiring verification, only one (referring to LM-7 rate gyro) is still active and should be resolved March 6. The Safety Office Assessment Report was presented at MSC's FRR on February 26, 1970. No constraining items exist. Two items are to be presented involving crew procedures.

March 20-26, 1970.- An R&QA review will be held during the afternoon and evening before the Apollo 13 launch to reaffirm launch, and results will be discussed with the CSM Manager. The mission plan and information notebook for the Apollo 13 mission is being prepared for Safety and R&QA mission support. The Safety Office provided the Deputy Manager with a written assessment of an R&QA single-point OPS/PLSS leakage failure. The Crew Systems Division is aware of the problem and is developing a work-around procedure.

April 3-9, 1970.- Open problems with potential Apollo 13 effectivity continue to be worked. Last planned status report to ASPO is scheduled for April 10, 1970. It is anticipated that all open problems will be closed or explained by that time.

April 10-16, 1970.- Final Apollo 13 Single Failure Point Summary was made during this time and approved by subsystem manager. All reported problems effective against Apollo 13 were closed or explained prior to launch. Also, all ALERTS for Apollo 13 were closed prior to launch. R&QA and Safety activities have been mainly to support changes in the mission brought about by loss of the oxygen supply.

Apollo 13 Mission Real-Time Activities

The Safety/R&QA functions support the premission and mission activities of Apollo flights in real time. The purpose of this support is twofold. First, the Safety/R&QA personnel, both in-house and contract, provide a contact for the mission group to call on for specialized support at any time during the mission from launch minus 9 days through splashdown. There are also specialized R&QA/Safety personnel available at the contractor's plants, NR and Grumman, for consultation as required. Secondly, the Safety/R&QA people are monitoring mission activities to make independent safety assessments and evaluations for future crew safety and mission readiness purposes. For this purpose, the monitoring team maintains a log of problems and occurrences that is used to prepare a support anomaly list that is later resolved with the Project Test Division in the preparation of the Mission Anomaly list. The Safety/ R&QA support operation for the Apollo 13 mission included the following activities:

Prelaunch. -

Daily problem closeout meeting: Meetings were held daily to review the status of hardware problems, certification tests, limited-life items, and other pertinent reliability concerns to assure that all potential problems had been properly evaluated and resolved. Headquarters R&QA was also represented at these meetings.

R&QA/Safety status meeting: A meeting of R&QA and Safety personnel was held on Friday evening, April 10, 1970, to review the status of all known and potential problems on Apollo 13. The meeting was chaired by the Manager, Safety and R&QA Offices. Following the meeting, the CSM Project Manager was informed of the results of the meeting. Headquarters R&QA was represented at the meeting.

Daily launch readiness problem report: This was initiated February 9, 1970, and the final report was issued on the morning of April 11, 1970, indicating no open problems against Apollo 13 hardware.

Daily bulletins: Apollo 13 bulletins were issued daily by the Control Center to keep personnel informed as to the status of Apollo 13 as it neared launch.

Countdown monitoring: Monitoring activities at MSC were initiated at T - 2 days and continued through the mission. Headquarters personnel maintained 24-hour monitoring of countdown activities at KSC up until launch.

Quality data review: MSC quality personnel at KSC reviewed IDR's DR's, etc., at KSC as the problems occurred to assure immediate evaluation of these problems.

Problem review and evaluation: Safety/R&QA participated in review and evaluation of hardware problems to determine potential mission impact. These included the lunar module cryogenic helium tank pressure rise problem and the oxygen tank umbilical quick-disconnect leakage occurrence.

Launch to accident. -

Monitoring activities: Real-time monitoring of Apollo 13 was maintained at MSC and in the GE Mission Evaluation Room offsite. A control center was also manned by contractor personnel on a 24-hour basis to provide a central focal point for all Safety/R&QA missions activities.

Daily bulletins: Bulletins reporting the mission status were issued daily.

Flight anomalies: As suspect flight anomalies occurred, they were posted in the Control Center. R&QA personnel were requested to review and evaluate these occurrences as soon as feasible after the events were reported.

Requests for support: Requests for R&QA support for Test Division or other NASA groups were received and were worked as required. Three such requests were received prior to the accident. These requests were for failure histories, failure mode evaluations, etc., on the cryogenic helium tank pressure rise problem, the ECS suit pressure transducer, and on the oxygen tank no. 2 quantity gaging probe problem.

Postaccident.-

Safety/R&QA activities immediately following the Apollo 13 accident concentrated on compilation of subsystem data to determine the factors involved in the safe return of the crew--including single failure points. It included:

Safe-return factors: Each spacecraft subsystem was reviewed to identify those areas and concerns affecting the safe return of the crew in the emergency Apollo 13 configuration. A "Safe Return Factors" book was compiled and made available for reference in the Planning Room (GE).

Quality data: The quality control data on the CSM 109 oxygen tank no. 2 was compiled and a search of these records for any questionable items was initiated.

Historical data: The historical data, including failures, on similar oxygen tanks were searched for evidence of significant problem areas, as was the test and checkout history of the CSM 109 cryogenic and EPS systems.

Flight data review Safety/R&QA: Personnel participated in the review of flight data as a part of a team.

Configuration review: A review of the equipment and its relative location in bay 4 of the SM was made.

Single failure points: A study was prepared listing all Criticality I SFP's in both the CSM and the LM based upon the emergency configuration of Apollo 13.

Unexplained anomalies: A review was made of each of the explained anomalies approved for Apollo 13 to determine any potential connection with the Apollo 13 accident.

Daily review meeting: An R&QA/Safety Review meeting was held daily at 4 p.m. c.s.t. on April 14-17, 1970, to review the status and progress of the activities listed in the preceding paragraphs. The Manager, Safety and R&QA, strongly emphasized during these meetings the need to concentrate on those activities affecting the safe return of the astronauts. The activities designed to determine the cause of the accident were pursued only when they did not interfere with this primary concern.

CONCLUSION

The MSC Safety/R&QA plans and procedures appear to be adequate and complete for their assigned responsibilities. Their maintenance of equipment and system records, identification of suspect and failure areas, and followup corrective actions through the Government and contractor organization are adequate. Monitoring of contractors is presently accomplished with onsite personnel and visits rather than by formal audits. This appears adequate at present but should be supplemented by formal audit visits whenever possible.

The preflight System Safety Assessments made for each flight of the Apollo Program are thorough and timely and the flight monitoring support of Safety/R&QA is good. The postflight anomaly identification and tracking system is good.

The Safety/R&QA area appears to be generally adequate with proper procedures, good organization, and well-motivated personnel.

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PART E10

SECURITY

Security surveys were conducted at Beech Aircraft Corporation, Boulder Division, and North American Rockwell Corporation, Downey, California, during the time period of April 27, 1970, through May 5, 1970.

The purpose of these investigations was to evaluate the adequacy of the security programs at each location during the time periods that the Apollo oxygen tanks were in custody at the respective industrial plants. An extension of the accident investigation involved reconstructing the security systems and procedures applicable to the oxygen tanks from the time of shipment from NR to KSC and through launch of Apollo 13 on April 11, 1970. To fulfill the stated purpose of this inquiry involved evaluation of security programs at Beech, NR, and KSC from April 1, 1966, through April 11, 1970.

The security programs at each contractor location were found to be satisfactory and adequate to provide for the physical protection of the oxygen tanks. The security procedures provided at KSC were found excellent and assured the integrity of all Apollo 13 hardware from initial receipt on June 26, 1969, through launch on April 11, 1970.

Federal and local agencies acquainted with the security programs at NR and Beech were contacted and gave favorable evaluations of each contractor's performance during the pertinent time period.

Industrial security files were reviewed for incidents involving the oxygen tanks at Beech and spacecraft 106 and 109 at NR. The results at Beech were negative, and the incidents located at NR have been reported for technical evaluation in the preliminary report submitted May 8, 1970, to the Review Board Chairman and Manager, Apollo Spacecraft Program Office.

The determination reached as the result of this survey is that no evidence was discovered that the failure of the Apollo 13 oxygen tanks was the result of any willful, deliberate, or malicious act on the part of an individual at the contractor facilities surveyed or at KSC. Physical security measures were sufficiently designed, implemented, and monitored so as to preclude unauthorized access to the hardware associated with this investigation.

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