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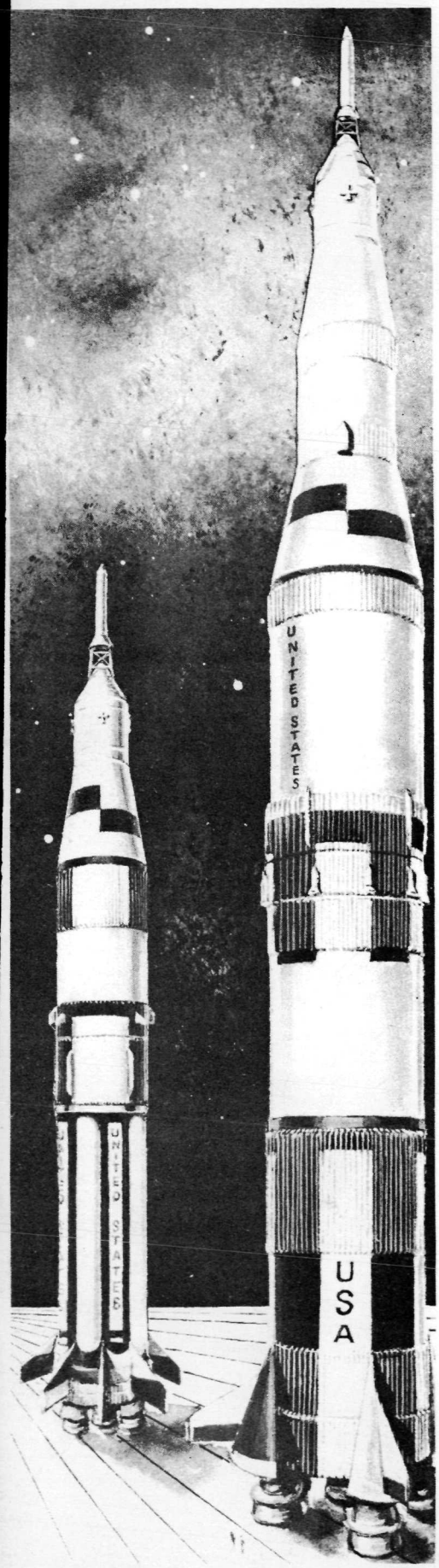

SATURN

NASA CR-129029

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THE SATURN MANAGEMENT CONCEPT

By
Roger E. Bilstein

June 1, 1974

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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16. ABSTRACT

Management of the Saturn launch vehicles was an evolutionary process, requiring constant interaction between NASA Headquarters, the Marshall Space Flight Center (particularly the Saturn V Program Office), and the various prime contractors. Successful Saturn management was a blend of the decades of experience of the von Braun team, management concepts from the Army, Navy, Air Force, and Government, and private industry. The Saturn V Program Office shared a unique relationship with the Apollo Program Office at NASA Headquarters. Much of the success of the Saturn V Program Office was based on its painstaking attention to detail, emphasis on individual responsibilities (backed up by comprehensive program element plans and management matrices), and a high degree of visibility as embodied in the Program Control Center.

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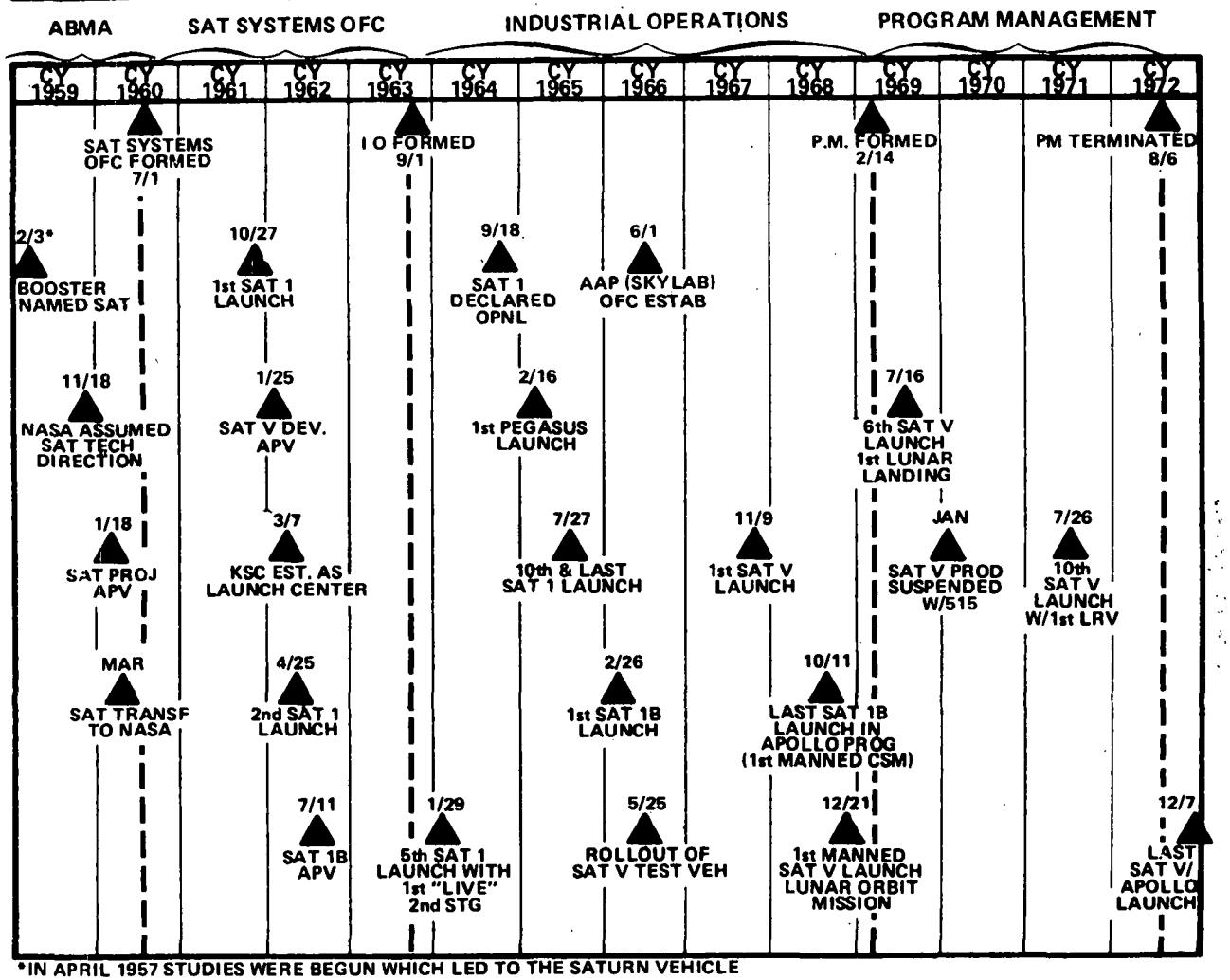
EVOLUTION OF SATURN MANAGEMENT PROGRAMS
MARSHALL SPACE FLIGHT CENTER



*IN APRIL 1957 STUDIES WERE BEGUN WHICH LED TO THE SATURN VEHICLE

PREFACE

This brief study is the result of the initiative taken in the spring of 1973 by the Saturn V Program Office (Richard G. Smith, Manager) of Marshall Space Flight Center, through its Program Control Office (Thomas S. Johnston, Chief). The study is intended to satisfy numerous requests by individuals, private enterprise, and other Government agencies for a record of how the Saturn V Program Office conducted its activities and how it succeeded in managing an enterprise as large and complex as the Saturn V launch vehicle. The study was prepared during the 1973 American Society for Engineering Education/National Aeronautics and Space Administration Summer Faculty Fellowship Program, conducted at Marshall Space Flight Center under the joint direction of the University of Alabama and Auburn University. The principal advisor for the study was Mack W. Shettles, Branch Chief, Saturn V Program Office. For their patience and assistance in support of this project, the author wishes to thank those individuals listed above, as well as Kenneth L. Rossman, Robert P. Shepard, William H. Savage, Edna W. Hunter, Peggy Potter, Harriet Askew, and the staff of the MSFC Historical Office, especially Mitchell R. Sharpe. The interviews mentioned in the Bibliographical Note and References do not do justice to the additional time and effort contributed by many of these people. The author also wishes to thank Dr. J. Edwin Rush, Director of Graduate Programs and Research at the University of Alabama in Huntsville, for office facilities and access to the files of the Saturn History Project.

It should be noted that the opinions and judgements expressed in this study are those of the author, and do not reflect official National Aeronautics and Space Administration or Marshall Space Flight Center policy.

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THE SATURN MANAGEMENT CONCEPT

The activities of the Saturn V Program Office cannot be divorced from the overall management philosophies of the National Aeronautics and Space Administration (NASA) and the Marshall Space Flight Center (MSFC). Moreover, the threads of continuity run backwards, past its organization in 1963, to the prior operation of the Saturn Systems Office, the Army Ballistic Missile Agency, and the work of the von Braun team during World War II. This historical summary and analysis is intended to place the evaluation of the Saturn V Program Office in a relevant historical perspective, and to describe its role in NASA's Apollo/Saturn Program.

BACKGROUND

In 1962, pausing to look back over a career in which he played a key role as a leader in rocket research, Wernher von Braun noted two significant factors of success. First, the group of German rocket experts, known as the von Braun team at NASA's Marshall Space Flight Center, had been what von Braun called a "fluid, living organization," as it was shaped by external forces and, also, as it responded to them. Secondly, von Braun noted the three decades of consistent activity at the forefront of rocket development, an activity conducted with a "singleness of purpose," in advancing the infant art of rocketry. "We have had only one long-range objective: The continuous evolution of space flight," he emphasized. "Ever since the days of the young Raketenflugplatz Reinickendorf in the outskirts of Berlin in 1930, we have been obsessed by a passionate desire to make this dream come true."

As he looked ahead toward the goal of a manned lunar landing, von Braun forecast the existence of a team numbering in the hundreds of thousands. This did not necessarily imply a drastic change in the approach to attaining the goal. There would be certain adjustments in style and techniques of management before Neil Armstrong set foot on the moon in 1969, but the managerial style evolved by the von Braun team over 30 years of experience persisted as a single thread of continuity. As von Braun himself remarked in 1962, despite the changes over the years in personnel, in geography, in nationality, and in bureaucracies, "many of our methods have remained unchanged."[1] It is significant that many of these methods remained current during the active life of the Apollo/Saturn Program, and carried over into other phases of management in astronautics at Marshall Space Flight Center.

In analyzing the success of the Saturn launch vehicle program, it is essential to remember the years of experience brought with the program by the von Braun team and to remember that a significant cluster of key personnel remained together from the 1930's onward. The von Braun "team" began with von Braun's assignment in the German Ordnance Department in 1932, where he had the assistance of one mechanic to engage in rocket development work. By the spring of 1937, when the group had grown to 80, the German Army sent orders to shift rocket work to a new research and test site at Peenemuende, located at the edge of the Baltic Sea. The most intensive work there occurred between 1942 and 1945, when the Peenemuende work force numbered about 10,000 and had constructed and launched approximately 3,000 missiles of the V-2 type.

The next cycle of activity brought the von Braun team to Fort Bliss, Texas, where 120 key personnel labored for the U.S. Army from September 1945 to April 1950. The hegira to Fort Bliss began in southern Germany in the closing weeks of World War II, when several dozen of the Peenemuende engineers and their families sought to avoid the advancing Russian armies. With sketchy information as to the location of the U.S. Army, the German rocket group headed towards southern Germany. At the same time, under the code name of "Operation Paperclip," a cadre of U.S. military intelligence personnel was scouring the countryside for high level German scientific and technical experts -- especially the group that had been responsible for the awesome V-2 rockets. The two groups finally linked up when Wernher von Braun's brother, Magnus, rode his bicycle down a country road in search of a U.S. Army intelligence unit.

The transition to the arid climate of the American Southwest was not easy. In the postwar era, research involving rocket weaponry languished, and "space flight was a concept bordering on the ridiculous." In more ways than one the early Fort Bliss period was, as von Braun phrased it, the "years of wandering in the wilderness" for the German rocket team. But work in rocketry still persisted, based on several dozen V-2 rockets captured in Germany and shipped back to Fort Bliss. The U.S. Army Ordnance Corps added 400 military personnel and civilians to the operation, and the Germans and their families became much more involved in American society and culture. Then in April of 1950, the Army transferred its rocket development work to facilities available at the Redstone Arsenal in Huntsville, Alabama. Six years later, in 1956, an important reorganization took place in the Army's rocket program. In order to get the short-range Redstone into operational status and into the field as rapidly as possible and in order to develop the Jupiter intermediate-range ballistic missile, the Army formally established the Army

Ballistic Missile Agency (ABMA), which quickly grew from a nucleus of about 1,600 to about 6,000 personnel. Moreover, in the course of Redstone and Jupiter development, the von Braun team began its first real work in developing rockets for missions into space.

Using modified versions of the Redstone and Jupiter, ABMA produced the launch vehicles that placed the first American satellites in orbit around the Earth, and next around the Sun. In addition, the ABMA establishment received the first orders to develop a large launch vehicle, based on the concept of clustered engines, that became known as the Saturn I. Crowded with events that marked the inaugural American ventures into space, the ABMA period lasted less than 5 years. With the creation of the National Aeronautics and Space Administration in 1958, the national program for the exploration of space was intended to be primarily a nonmilitary venture. NASA authorized the Marshall Space Flight Center at Huntsville on July 1, 1960, and the heart of the new NASA facility was transferred directly out of ABMA, comprising the von Braun group with over 4,000 personnel and $100,000,000 in equipment and rocket hardware.[2]

As Director of the newly formed Marshall Space Flight Center, von Braun faced some immediate managerial challenges. The core of the MSFC staff had come from ABMA's Development Operations Division, which he had directed for the Army. But the Development Operations Division essentially had been a research and development group depending on other ABMA offices for ancillary support and administrative services (Fig. 1). After the transfer to NASA, the new MSFC Director had to develop an administrative as well as technical staff, in addition to correcting the lack of offices for procurement contracting, facilities engineering, and other support services (Fig. 2). The von Braun team not only found itself in a civilian organization for the first time, but the style of operations had also changed, as there were now responsibilities for numerous projects as opposed to the ABMA experience of dealing with only one prime project at a time, phasing from one program to the next.[3]

Nevertheless, in spite of the increased scope of management responsibilities under the MSFC organization, the management style there retained a distinctive in-house capability -- what von Braun liked to call the "dirty hands" philosophy. The in-house capability, buttressed by the years of active work as a research and development group in Germany and by the arsenal concept of the ABMA days, provided an exceptionally strong number of laboratories and shops at the Huntsville facility. Managers and engineers were never very far away from each other, and the maintenance of the relationship (and its elaboration) persisted as a key element in the success of MSFC's management of the Saturn Program.

ARMY BALLISTIC MISSILE AGENCY

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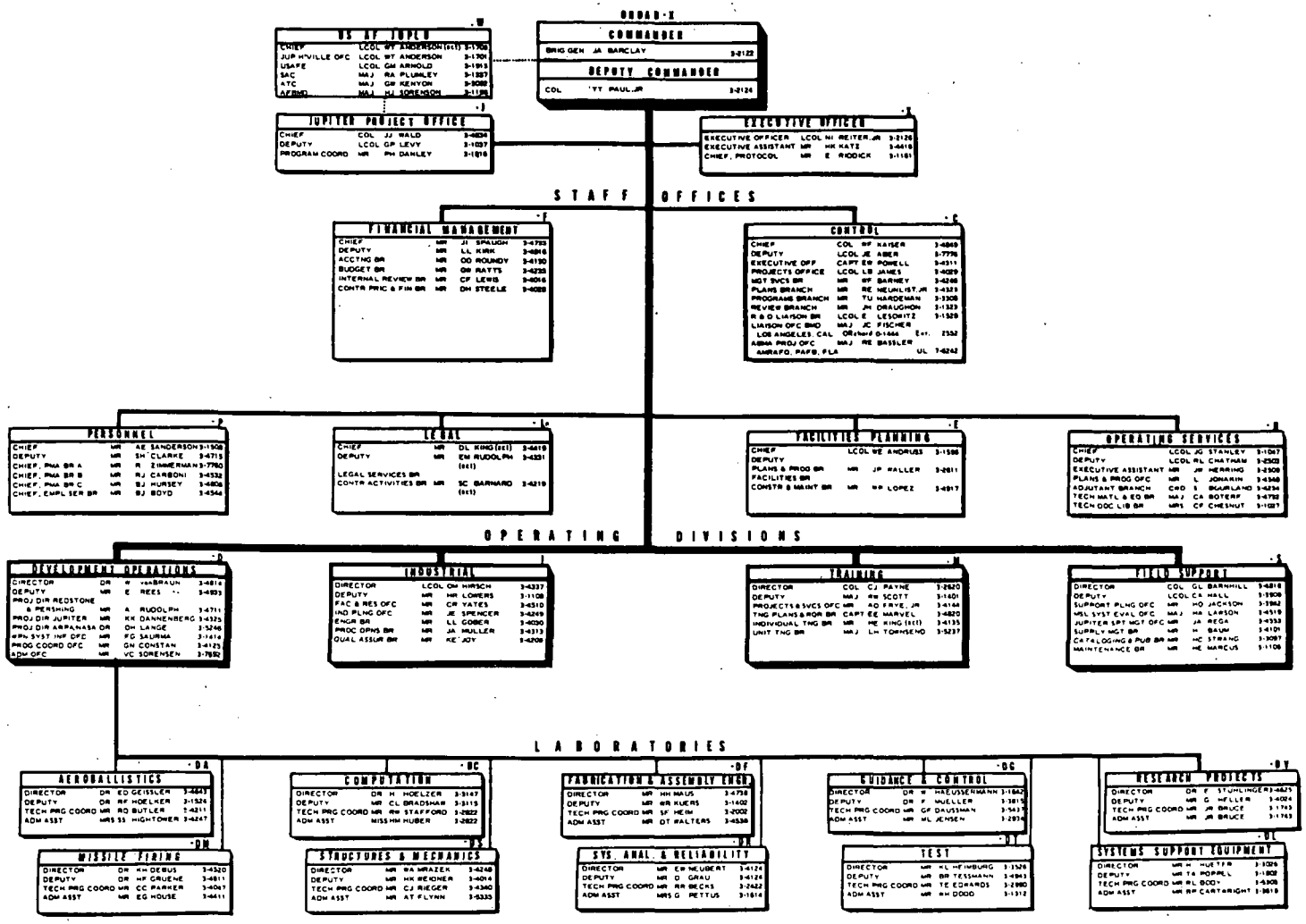


Figure 1. ABMA organization prior to formation of MSFC.

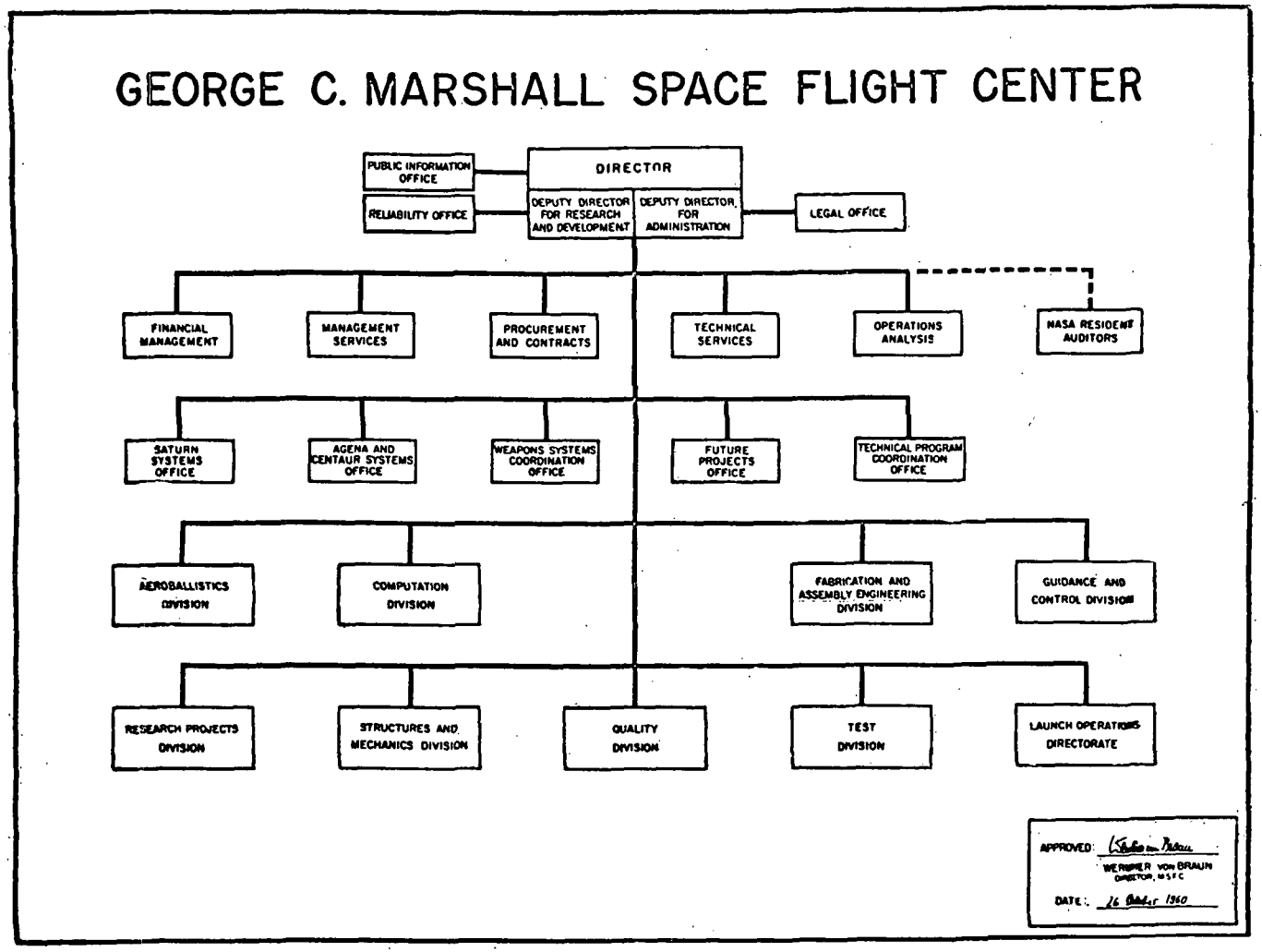


Figure 2. First MSFC organization chart.

EARLY SATURN MANAGEMENT

Eberhard Rees, who succeeded von Braun as MSFC's Director in 1970, said that when the Apollo/Saturn Program was inaugurated in the early sixties, the adolescent NASA organization really had no comprehensive management apparatus, and the management system developed "after some painful experiences" during the early development period. The management organization for the overall NASA program, as well as for MSFC, was not set up in a flash of insight, to remain unchanged for the duration of the program. Rather, as the program gained momentum and the configuration of the launch vehicles themselves began to evolve, management organization and tools began to evolve, but they always changed as the programs changed over the years. As Rees observed, one of the axioms in the evolution of a large development project was that no static system of management would suffice.[4]

The management setup for the early period of the Saturn Program, when the Saturn I was the only launch vehicle being developed, relied on the Saturn Systems Office (SSO). At the heart of SSO were the three project offices: Vehicle Project Manager; the S-I Stage Project Manager; and the S-IV/S-V Stages Project Manager. The Vehicle Project Manager cooperated with the stage managers in overall vehicle configuration and systems integration (the S-V was a small third stage concept that was ultimately dropped from the Saturn I configuration and should not be confused with the Apollo/Saturn V launch vehicle). The Saturn I first stage was produced and manufactured in-house by MSFC at Huntsville, and the production of the upper stages as well as the engines and the Instrument Unit involved comprehensive, but no burdensome, management of several other contractors. The SSO was a comparatively small program office, even up to the spring of 1963 when it numbered only 154 personnel. Its operation was based primarily on the strength of other Center administrative support offices and the work of what were known as the "line divisions." The latter were based on the nine technical divisions, or laboratories (numbering several hundred personnel each), carried over nearly intact from the ABMA days.

The laboratories themselves carried significant prestige within the Center's operation, and tended to benefit from very strong support from von Braun. In fact, most of the technical and design decisions were reached by consensus during the "board meetings" which included von Braun and the lab chiefs in executive sessions. Since the lower stages of the Saturn I vehicles were produced in-house, this proved to be a workable arrangement, and it must be rembered that the lab chiefs had worked this way for years, first at

Peenemuende and later at ABMA. It was not until the launch of the fifth Saturn I vehicle, SA-5, that a live upper stage was carried -- the S-IV stage, manufactured by the Douglas Aircraft Company (later McDonnell Douglas Corporation).[5] The launch of SA-5 occurred January 29, 1964, several months after a major MSFC and Saturn Program reorganization occurred designed to accommodate the growing scale of contractor work, as opposed to the traditional in-house style of rocket development by the von Braun team. Much of the work in SSO concerned funds and liaison with NASA Headquarters. This was conducted in a very informal manner, with SSO personnel frequently visiting in Washington with Headquarters personnel.[6]

The growth of the Saturn Program to include development of two new launch vehicles resulted in a reappraisal of the production and management organization. During 1962, the finalization of plans for a two-stage Saturn IB (for earth-orbital manned Apollo hardware tests) and the three-stage Saturn V (for the manned Apollo lunar landing missions) enlarged the scope of SSO and prompted the shifting of MSFC into what was to become primarily a management role. The change was underscored by von Braun in remarks to a management convention in 1962 when he observed "our rocket team has become today more than ever a managerial group." It was felt that the Saturn IB and Saturn V manufacturing programs were far beyond the in-house capability of MSFC and available Government resources, requiring large scale contracts under MSFC management instead. However, the diversity of the major contractors and subcontractors, scattered coast-to-coast, suggested a management challenge beyond the logic of the existing apparatus (Fig. 3). Compounding the task of developing and integrating two or three large, complex stages and an instrument unit into a single vehicle that would mate with the spacecraft and launch facility, were the multidiscipline problems of weight, size, and man-rating (Fig. 4). The complexity was further increased by budgetary constraints and tight schedules. "In solving this management problem, NASA and Marshall modified existing and other agency management techniques, devised new ones, and then changed them again as the situation demanded."[7]

The reorganization of SSO in 1962 combined the similar Saturn I and IB vehicles under the management of a single office, established the Saturn V Launch Vehicle Office, and set up the Saturn/Apollo Systems Integration Office. The technical divisions of MSFC did not change much under the new NASA organization and continued to report directly to von Braun, although their functions in support of MSFC programs were basically those of before. The divisions were not aligned specifically to projects, but were organized along professional disciplines such as electronics, mechanical engineering, flight mechanics, and so on. Each division director had the responsibility to

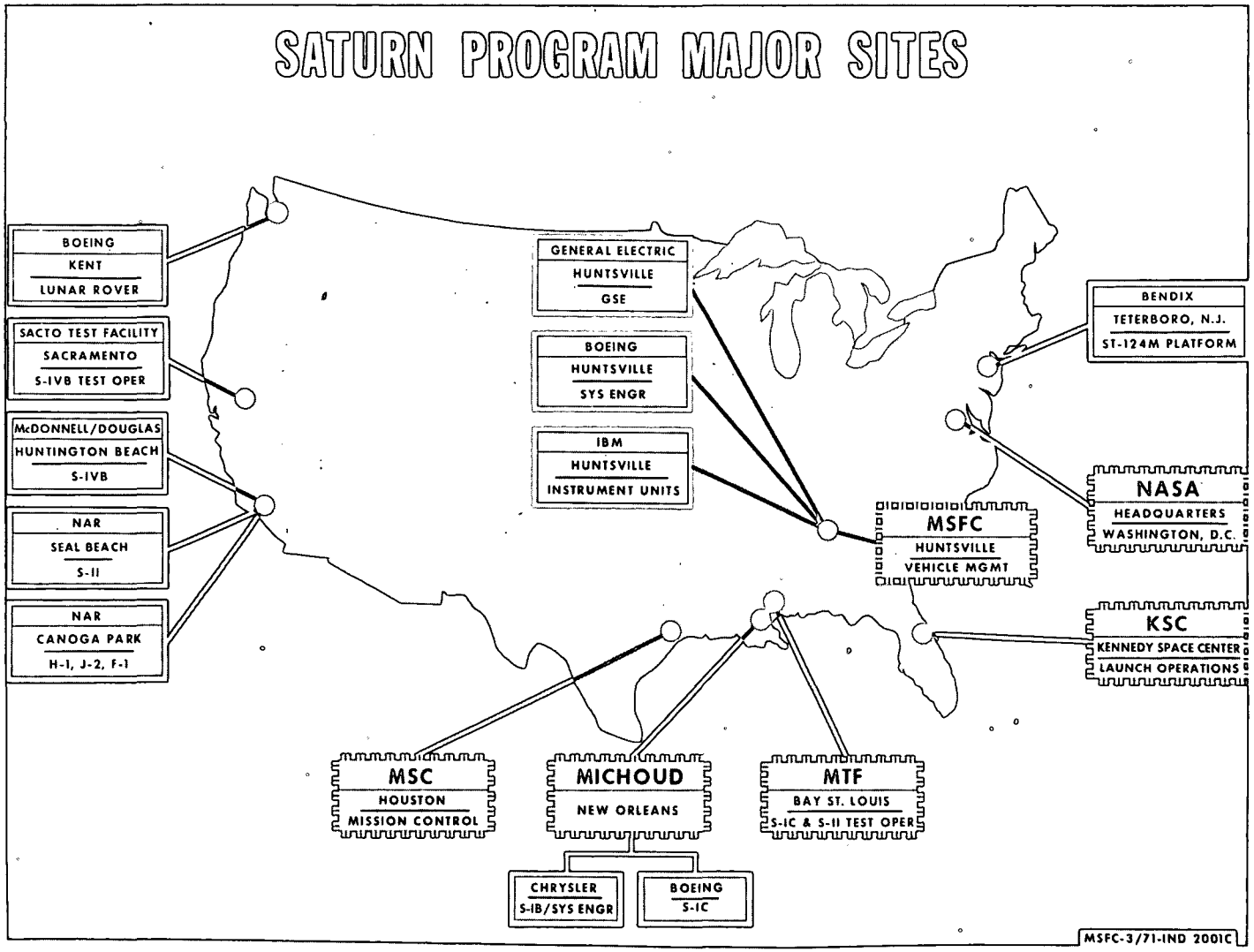


Figure 3. Major Saturn contractor locations.

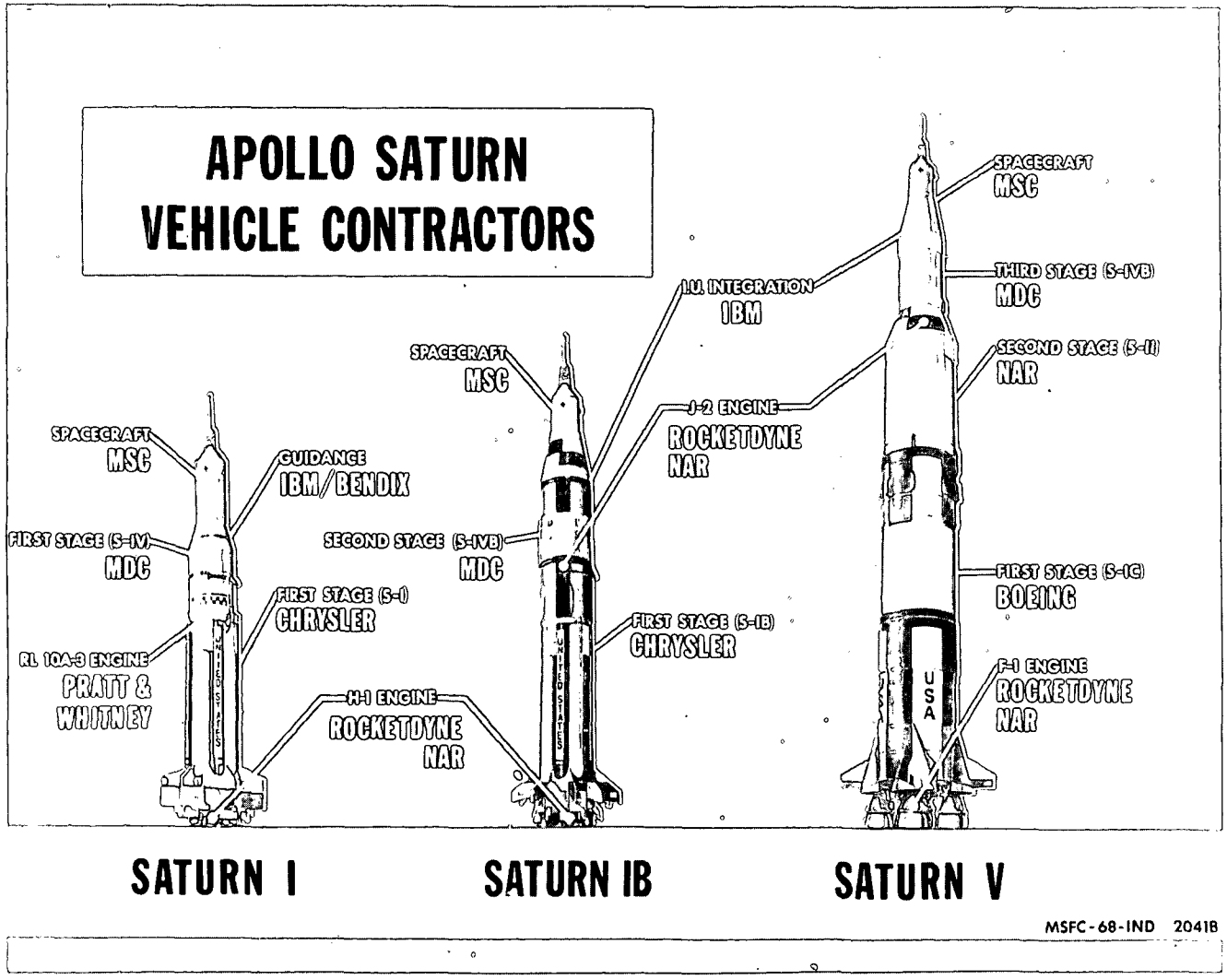


Figure 4. Saturn vehicles and prime contractors.

maintain a high level of expertise in his organization, keeping up with work in industry and other Government agencies and carrying on theoretical research. But, von Braun emphasized, "The technical people (must) keep their hands dirty and actively work on in-house projects selected specifically for the purpose of updating their knowledge and increasing their competence." Through such research and development work to stay abreast in the field, MSFC could command the respect of the contractors' professionals and stay involved in all phases of development, production, and shop work. This was the best way to maintain evaluation of contractor standards and evaluate proposals, von Braun emphasized. It was a matter of achieving the best economics in overall work, and in getting the maximum for taxpayer dollars.[8]

The same essential management style that persisted over the years remained valid in 1962, von Braun said. In the approach to a new project for development, the habit was to objectively assess a multitude of ideas and complementary studies, with wide use of opinions from outside sources. Most importantly, the Project Director exerted considerable influence, assuring the crystallization of objectives, designs, and individual responsibilities. A procedure for systems management was set up, and schedules for development and test were set up, "which, from then on, is the holy gospel of the project." In the normal course of events, substantive decisions contradictory to the original base line of progress occurred only in unforeseen emergencies. If the planning work had really been done well beforehand, he emphasized, no real perturbations need arise. Should a serious hiatus occur, "there is usually something wrong with either the engineering concept or with the ratio between the implementation plan and the resources committed to it." The need for flexibility was evident, because problems did occur, and it was necessary to have an organization that was capable of making adjustments.[9]

These basic tenets were followed during other phases of the Saturn Program and were most evident in the operations of the Saturn V Program Office as it functioned from 1963 to 1969, following a major reorganization of NASA Headquarters and the various Centers that occurred in the autumn of 1963.

REORGANIZATION OF 1963

As the momentum of the Apollo/Saturn Program increased and the activities of NASA Headquarters proliferated in response to the manned lunar landing program and other diverse NASA responsibilities, a major reorganization was planned to cope with all of the expanding operations (Figs. 5 and 6).

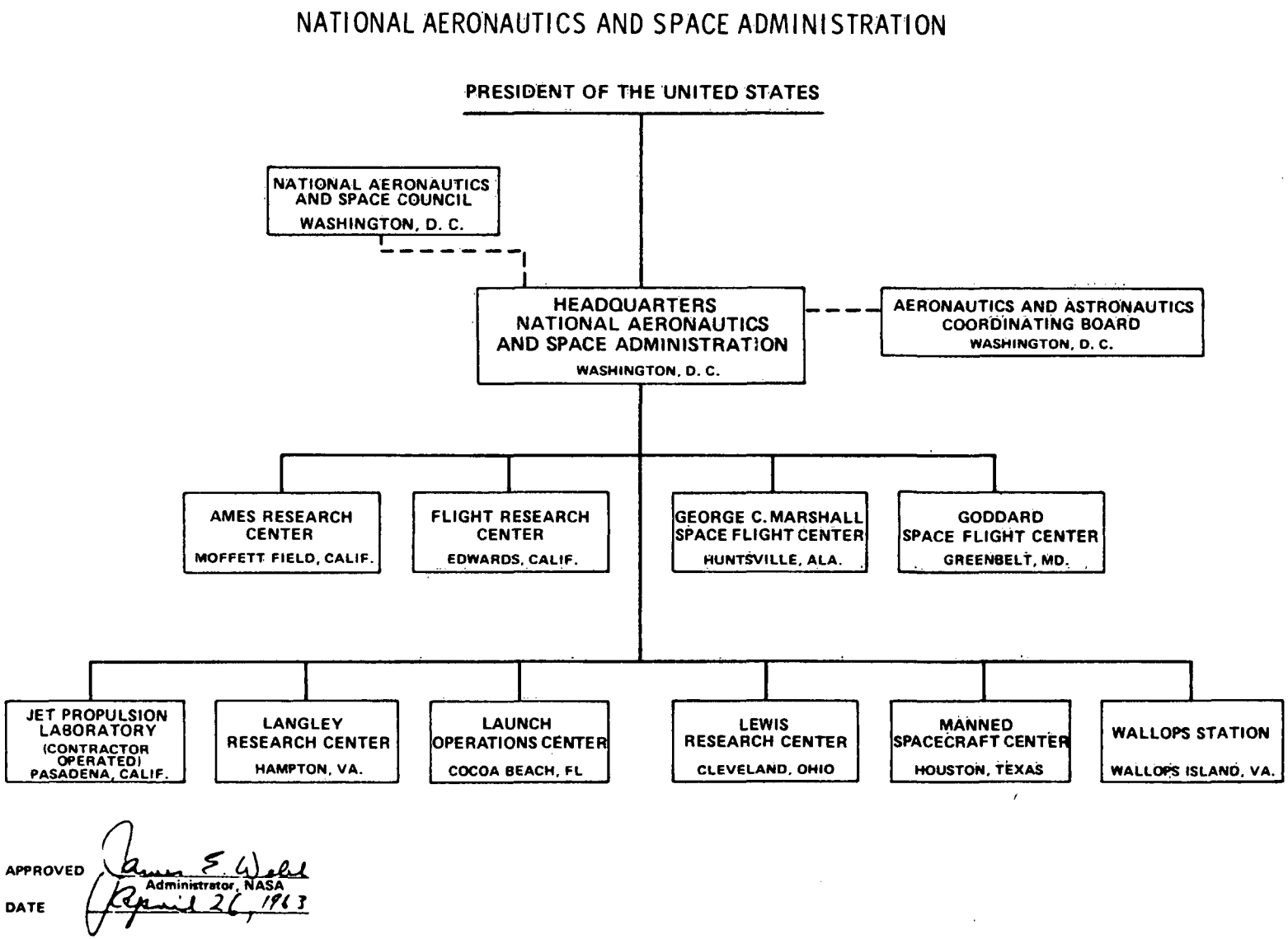


Figure 5. NASA organization in April 1963.

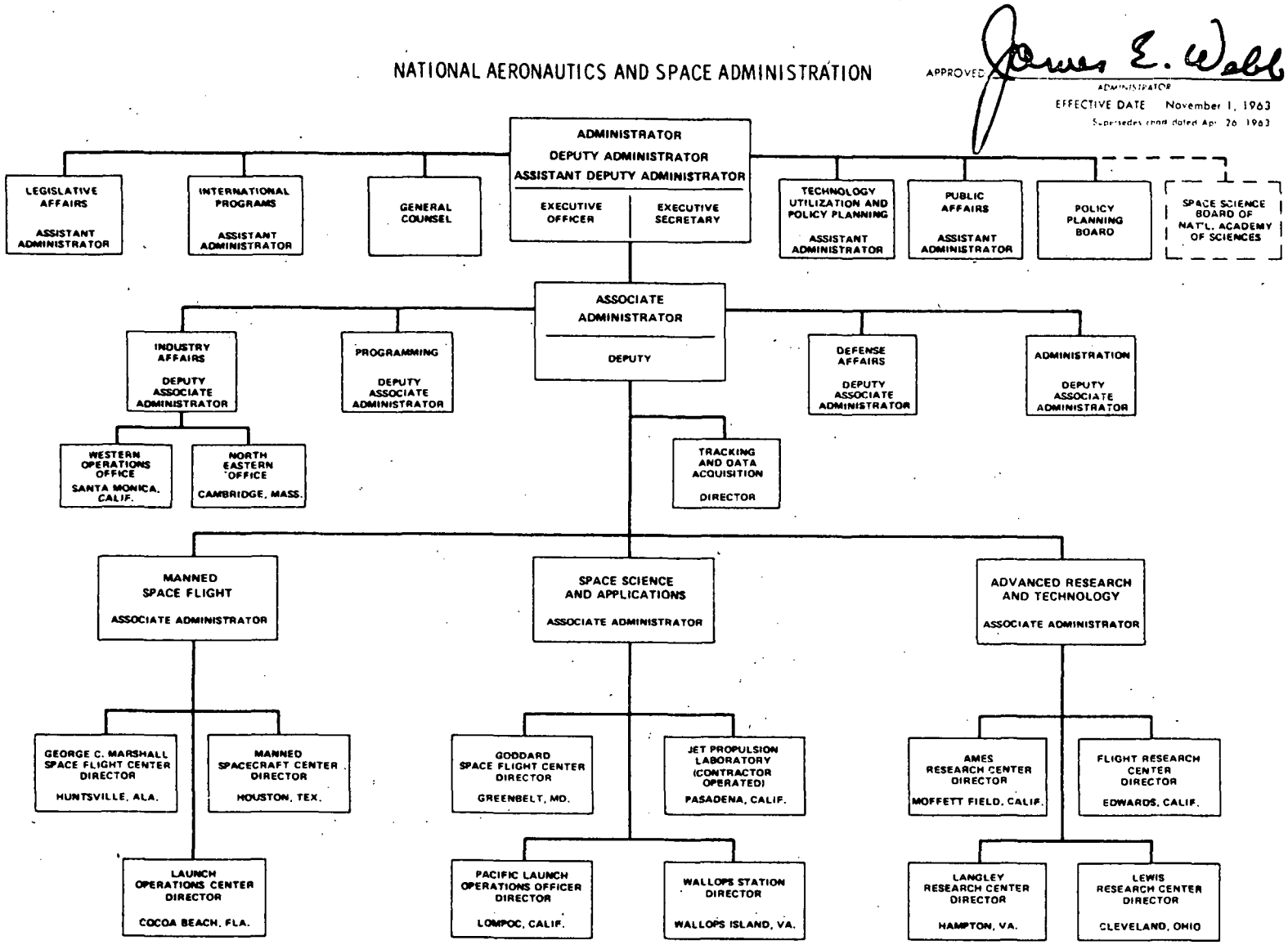


Figure 6. NASA as reorganized for the Apollo Program.

The reorganization involved all of the major Centers taking part in the Apollo/Saturn Program,[10] and the change that occurred at Marshall Space Flight Center set the style for its operations for the next 6 years, when development of the Saturn V launch vehicle was the most concentrated. The change at MSFC revealed a strong reflection of past organizational arrangements, but also increased the authority of certain segments of the managerial structure and established very successful new working arrangements between NASA Headquarters and MSFC, and within MSFC's new organizational framework (Fig. 7).

Effective September 1, 1963, the reorganization at MSFC established the Center Director's Office (with appropriate staff and functional offices) directing two new operational segments: the Research and Development Operations (R&DO) and Industrial Operations (IO). Both of the new organizations possessed equal operational authority, and both reported directly to von Braun as Director of MSFC.[11] Operations between the two, however, were continuous, and certain elements on the IO side had a direct and continuous relationship with NASA Headquarters.

In essence, the laboratories for R&DO were direct descendants of the older technical divisions, while the basis for the IO elements were modifications of the former Saturn Systems Office. At the heart of the IO organization were the three program offices, established for the direct management of the industrial contractors who had responsibility for the Saturn launch vehicles: the Saturn I/IB Office, the Saturn V Office, and the Engines Office. The latter was new, shifting responsibility for engine development and production from the laboratories to the IO side of the organizational chart, in keeping with the intent of the 1963 reorganization for better management control by means of program and project management.[12]

Each of the program offices was set up similar to the parent IO organization, so that each Program Manager had a cluster of small, dual-purpose staff and functional offices, in addition to the Project Offices for technical management. There was some combining of closely structural elements. The Saturn V Program Office, for example, managed the S-IVB stage, used on both the Saturn IB and Saturn V. Similarly, with certain of the engines used in more than one stage or vehicle, direction of the engine program was more effectively guided from one responsible Engine Program Office.

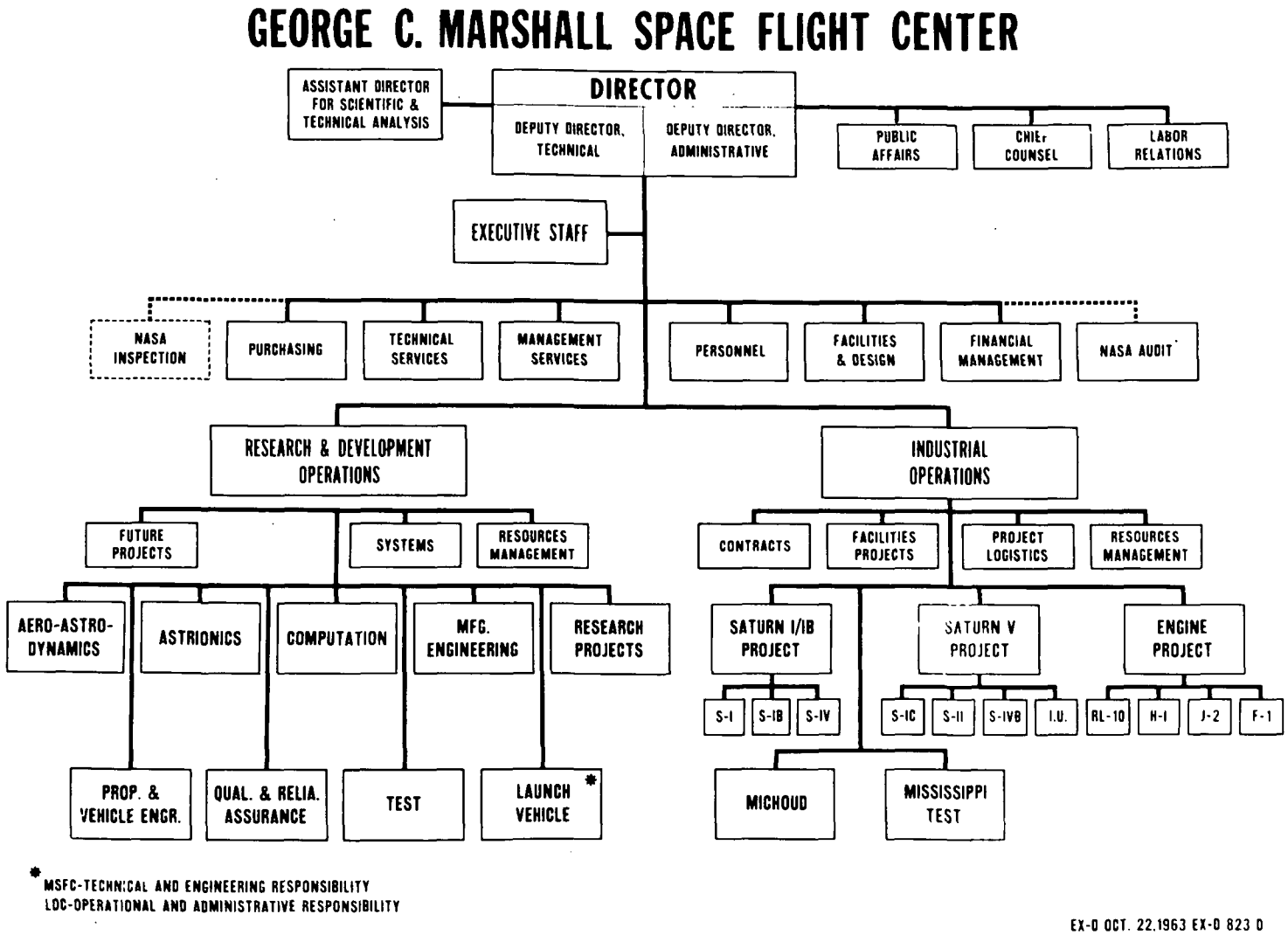


Figure 7. MSFC reorganization of 1963.

Arthur Rudolph, head of the Saturn V Program Office, emphasized that the managers of the staff and functional offices were not simply "staff" but equal to the Project Managers for each of the project offices under Rudolph's jurisdiction.[13] The staff and functional offices had multiple roles, insofar as they supported not only the Program Manager but each of the Project Management offices and interfaced with NASA Headquarters as well. They were known informally in NASA circles as the "GEM Boxes" after George E. Mueller, who headed the Office of Manned Space Flight.

Formal guidance and direction from Headquarters to the Centers came down through the Associate Administrator's Office, to the Center Director, and to the Program Manager, but daily informal management was accomplished through the GEM Boxes, which provided a "mirror image" between Headquarters and the Centers (Figs. 8 and 9)[14]. The GEM Boxes in the Centers were identical to those in Mueller's office in Washington, D.C., and facilitated a daily, and free, flow of information in both directions. "Since like persons were talking at both ends," commented one long time observer of the system, "confusion and misunderstanding with accompanying loss of time and funds were held to a minimum." The impetus for this aspect of the managerial apparatus primarily came from Mueller himself. During visits to MSFC, Mueller emphasized to von Braun that the labs (R& DO) were really going to have to adopt more of a support role in terms of the new program management structure, and that better communications with Headquarters through IO were urgently required. Mueller felt that the Centers in general were too independent in their Headquarters relationships and that the lack of communications, on a regular basis, was a serious shortcoming, "So I put together this concept of a program office structure, geographically dispersed, but tied with a set of functional staff elements that had intra-communications between program offices that were below Center level and below the program office level so as to get some depth of communications."[15]

THE SATURN V PROGRAM CONTROL SYSTEM

Following the 1963 reorganization, the new program offices began to formulate their mode of operations. As head of the Saturn V Programs Office, Arthur Rudolph called on considerable managerial expertise in project management of rocket vehicles dating back to the years at Peenemuende, and especially during the ABMA period when he served as Project Director for the Army's Redstone and Pershing programs. During 1961 through 1963,

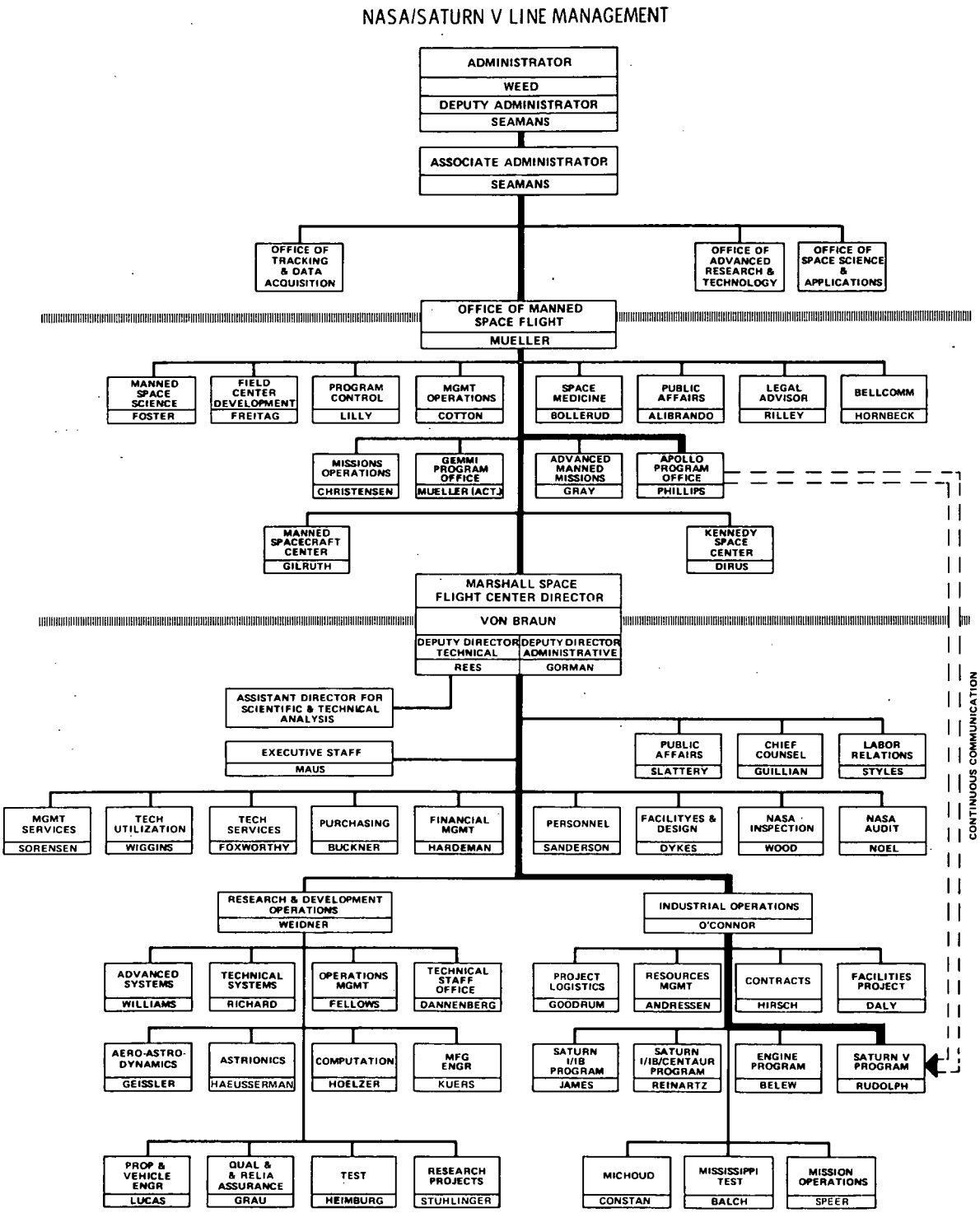


Figure 8. NASA Headquarters/MSFC relationships.

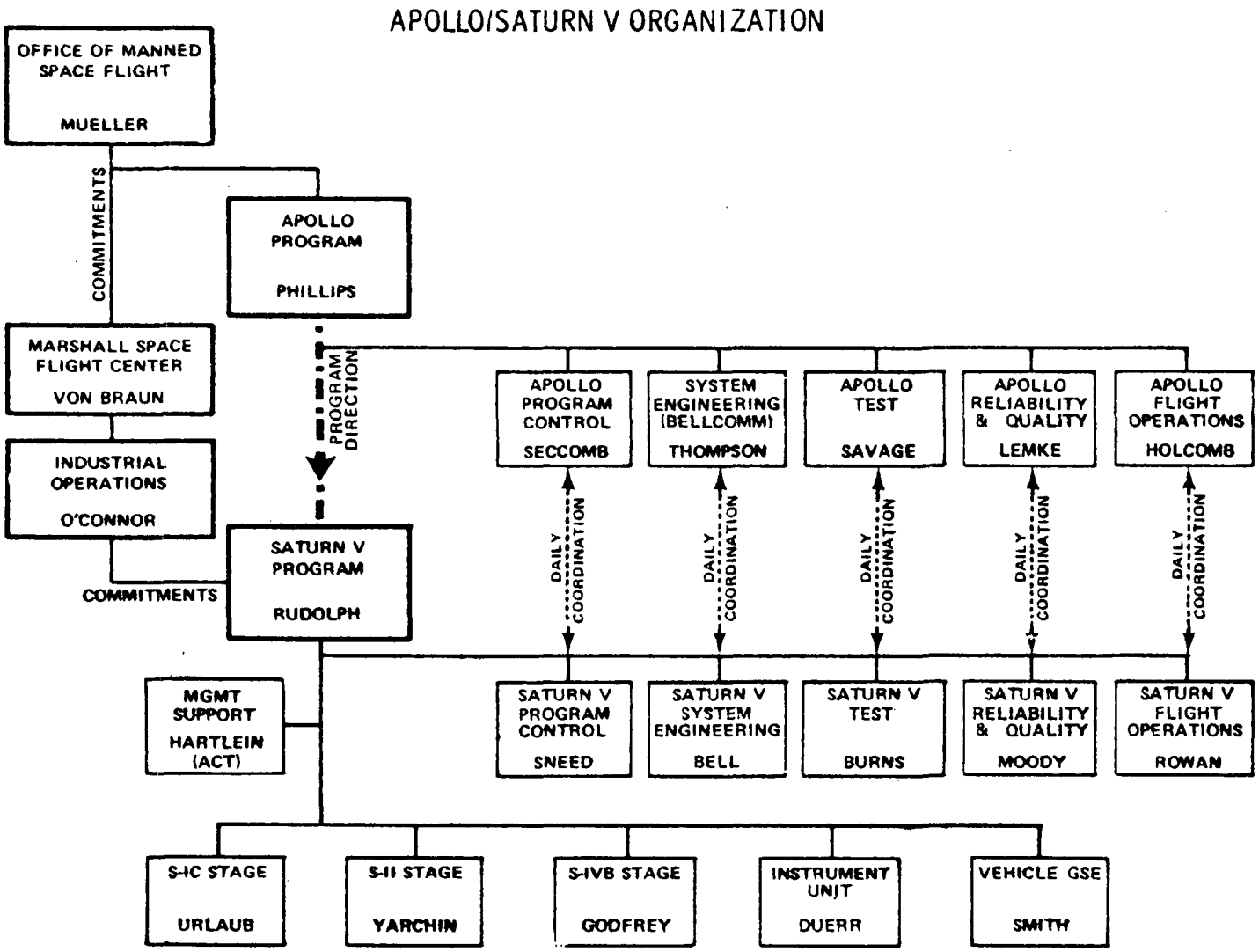


Figure 9. The "Mirror Image" or "GEM Box" concept.

he had also worked at NASA Headquarters, in the Systems Engineering division of the Office of Manned Space Flight. From that perspective, he had watched the plans for the Saturn V evolve, and was already cognizant of such factors as schedules, funds, and performance requirements.[16] He also had specific ideas of how his program was going to run, and placed considerable emphasis on what he called Program Element Plans (PEP). Rudolph's staff often chafed under the requirements to write up these rather specific PEP documents, which detailed what each office was going to do and how it was going to be accomplished. But most of the skeptics finally came around. The PEP's really forced people to think about the goals and mechanics of their respective operations and how they interacted with other offices. Even if they seldom referred back to the documents, they proceeded with greater success, having been forced to think through the procedures from the start, eliminating potential roadblocks and pitfalls. "I think the major problem is that in big programs like the Saturn V you have many people involved and usually people want to go off on tangents," Rudolph explained. "And the biggest problem is really to get them all to sing from the same sheet of music, to put it in the simple fashion. That's the biggest problem."[17] James T. Murphy, who acted as Rudolph's Deputy Manager, Management, summarized the role of his chief: "In its simplest concept, a program manager, with a supporting staff, has been designated to coordinate the efforts of all Government and private industry groups in developing and producing the Saturn V Launch Vehicle."[18]

A major instrument in establishing a managerial approach to this end was the Saturn V Program Control System Plan, originated by Rudolph's office in 1965, as Directive No. 9. The plan's objective was to establish a method to set up a "baseline definition," against which progress could be plotted, problems highlighted, corrective actions taken, and management kept informed. Directive No. 9 instructed personnel in the Saturn V Program Office to augment the management approach in five major areas:

1. Baseline Definition
2. Performance Measurement and Analysis
3. Problem Resolutions
4. Management Reporting System
5. Program Control Center

The baseline definition was primarily geared to matters of cost, schedules, and performance, achieved through program elements such as logistics, finance, testing, and so on. The program elements comprising the baseline definition were under the control of the staff/functional offices known as the GEM Boxes.

Brief Description of Five Mueller Boxes

Program Control Office: Primarily responsible for costs and budgets, progress report, and logistics including manpower and facility requirements, scheduling and contracts, and configuration management.

Systems Engineering Office: Responsible for mission description, overall systems specifications, and systems description.

Test Office: Charged with test planning, performance, coordination and standards, and for the establishment of checkout requirements and coordination.

Reliability and Quality Office: Responsible for establishing and maintaining reliability and quality standards, including contractual requirements, compilation of statistics, and failure reports.

Flight Operations Office: Charged with assuring that all flight hardware was ready for manned flight operations, including the establishment of necessary requirements, plans, and coordination.

Each of the staff/functional offices was required to set up a Program Element Plan to achieve the following:

Program Element

1. Management Plan
2. Schedule Control System Plan
3. Procurement/Contracts Plan
4. Documentation Plan
5. Configuration Management Plan
6. Equipment Management Plan
7. Logistics Support Plan
8. Facilities Plan
9. Manning Requirements
10. Finance Plan
11. Technical Requirements and Definitions
12. Reliability and Quality Assurance Plan
13. Testing (Master Test Plan)
14. Launch and Mission Operations Plan
15. Data Interchange Plan
16. Growth Potential Proposal

Each office involved in the Program Element Plan was further instructed to formulate a Program Directive to implement its respective tasks, and to establish authorities and responsibilities. All of this information was submitted through the Program Control Office for approval by the Program Manager.

Once the program element requirements and objectives were established, each office with program element responsibilities was expected to maintain the monitoring and assessment of its activities, in terms of "Performance Measurement and Analysis." In the case of difficulties in the program, the "Problem Resolution System" (developed by the Program Control Office) was to be implemented. Having identified the problem and assessed its impact, the requirement was to follow through by assigning appropriate personnel and resources, determine a solution, and close out the problem (Fig. 10). The Program Control Office also was responsible for the adequacy of the "Management Reporting System." This applied to recurring as well as unscheduled reports to management personnel, and the dissemination of program data within the procedures for the respective Program Element Plans. Finally, there had to be a focal point for the display of baseline data, in order to measure performance against it. Again, the Program Control Office was to cooperate in setting up display requirements for each office with a program element responsibility, and to operate and maintain the "Program Control Center" as this focal point.[19]

Obviously, the Saturn V Program Control System was only one aspect of a workable managerial approach, which included a number of groups and systems in support of the concept of Program Management at MSFC. Additional facets of the managerial mix included Inter-Center Coordination, Working Groups, and Management Matrices, as well as a number of other managerial tools (like PERT and SARP), other offices (such as those on the on-site resident managers), and other managerial tools.

INTERFACES AND INTER-CENTER COORDINATION

There was a myriad of interfaces to be controlled throughout the Saturn Program, such as those between stages, between the payload and the vehicle, and between the vehicle and the launch facilities. With contractors and three major NASA centers in the Apollo/Saturn Program, the interface problems covered physical, functional, and procedural areas, which often became intertwined. The documentation included both drawings and written directives

SATURN V TOP CRITICAL PROBLEMS

SYSTEMS ENGINEERING MANAGER—LUCIAN BELL I-V-E
PROJECT CONTROL - ORVILLE SMITH

PROBLEM NUMBER	PROBLEM	IMPACT	POSSIBLE SOLUTION	STATUS	FURTHER ACTION	IO/R & DO CONTACT	RESOLUTION DATE
1	• 110A GROUND COMPUTER SYSTEM UNRELIABILITY.	• FAILURE OF LAUNCH CRITICAL COMPONENT MAY RESULT IN A LAUNCH SCRUB.	• ELIMINATE DESIGN ERRORS. • GET RCA MORE INVOLVED IN OPERATIONS AT KSC. • IMPROVE EFFECTIVENESS OF IBM OPERATIONS AT KSC.	• THE 110A GROUND COMPUTER SYSTEM RANKED SECOND IN TOTAL ENCOUNTERED REPAIR TIME AND FIRST IN TOTAL ENCOUNTERED FAILURES OF ALL SYSTEMS IN THE BOEING SA-504 SIMULATION MODEL AND IS BASED ON 200 LAUNCH ATTEMPTS. THESE LAUNCH ATTEMPTS ARE CONSIDERED TO BE REPRESENTATIVE OF SA-501, SA-502, AND SA-503 LAUNCHES. • TWO (2) LOGIC DESIGN ERRORS ACCOUNTED FOR THREE (3) OUT OF SIX (6) CDDT PROBLEMS IDENTIFIED. THESE THREE (3) PROBLEMS WERE RESOLVED BY RCA ECP'S 275 & 282. THE REMAINING THREE (3) ARE STILL UNDER INVESTIGATION BY RCA.	• INCORPORATION OF RCA ECP'S 275 & 282. • RCA COMPLETE INVESTIGATION OF UNRESOLVED PROBLEMS ENCOUNTERED DURING 501 CDDT. • A TENTATIVE MEETING BETWEEN MSFC & KSC, TO BE HELD AT KSC, IS PLANNED TO RESOLVE RECENT CDDT 110A COMPUTER PROBLEMS.	L. SOMMERS I-V-G J. LEWIS R-ASTR-NDG	UNKNOWN.
2	• INTERFERENCE WITH HOLD-HOLDOWN ARMS.	• UNKNOWN DAMAGE TO VEHICLE.	• NO SOLUTION REQUIRD FOR SA-501,502 & 503. • SOLUTION FOR SA-504 & SUBSEQUENT TO BE DETERMINED.	• BASED ON MEASUREMENTS & DATA, R&DO CONCLUDES CLEARANCES ARE ADEQUATE FOR AS-502 LAUNCH. • PRESENT DATA INDICATES CLEARANCES ARE ADEQUATE FOR AS-503 LAUNCH. • R&DO WILL CONFIRM CLEARANCES FOR AS-503 BASED ON SPECIFIC AS-503 MEASUREMENTS & DATA WHEN AVAILABLE. • AS-504 CRITERIA UNDERGOING FURTHER ANALYSIS & WILL USE AS-501,502,503 DATA.	• NONE FOR AS-502. • CONFIRM ANALYSIS OF AS-503. • CONTINUE STUDY FOR AS-504 & SUBS.	HAGOOD-R-AERO R-P&VE-V,S	BY AS-503 FLIGHT
3							
4	• APOLLO PROGRAM DIRECTIVE NUMBER 23 VEHICLE MATERIAL/ FLUIDS COMPATIBILITY).	• MAY IMPACT LAUNCH SCHEDULE IF INCOMPATIBILITIES ARE FOUND. • MAY IMPACT COST.	• AN ANALYSIS BY I.O. & R&DO TO DETERMINE IF MATERIALS/FLUIDS COMPATABILITY DATA EXISTS • PERFORM STUDIES & TESTS TO DETERMINE MATERIALS/ FLUIDS COMPATIBILITY IN THOSE AREAS WHERE DATA IS LACKING.	• R-P&VE-M ANALYZING STAGE CONTRACTORS FLUID/MATERIALS DATA & TEST PROGRAM IMPACTS. • R-P&VE-M TO PROVIDE PROPOSAL TO RETRIEVE DATA AND TEST PROGRAM PROPOSAL. • GEN. PHILLIPS TWX REQUESTS STATUS OF APD NO. 23 BY FEB. 18, 1968.	• ANALYZE CONTRACTORS TEST PROGRAM IMPACTS & DATA. COMBINE INTO A MSFC TEST PROPOSAL. • SUBMIT TEST PROPOSAL TO APO FOR APPROVAL & FUNDS.	P&VE-M P&VE-M/I-V-E	MAR. 1, 1968 APR.1, 1968
5	• QUESTIONED CRYOGENIC STRENGTH OF MATERIALS. (LEWIS REPORT)	• POSSIBLE STRUCTURAL FAILURE.	• PROOF TEST AT CRYOGENIC TEMPERATURES.	• MSFC AGREED (STRUCTURAL DCR JAN 5) TO FLY AS-502 & UNMANNED AS-503 AS IS. • APO REQUSTED COST & IMPACT OF CRYOGENIC PROOF TEST OF MANNED VEHICLES. • APO TENATIVELY APPROVED CRYOGENIC PROOF TEST OF MANNED VEHICLES. • CRYOGENIC TEST WOULD REQUIRE RETURNING AS-503 STAGES TO MTF.	• PREPARE CRYOGENIC TEST PROPOSAL. • MONITOR TEST PROGRAM & IMPACTS. • STATUS LETTER IN COORDINATION. GEN. O'CONNOR	R&DO-KINGSBURY/R-P&VE-M GODFREY/ I-V-S-H HARBER/I-V-E	TO BE DETERMINED
6	• ABORT DURING MAXIMUM Q.	• RESULTING EXPLOSION MAY CAUSE CREW LOSS.	• ACCEPT RISK. • CHANGE ABORT SEQUENCE (REQUIRES VEHICLE MODS.)	• TESTS AND BEEF-UP COMPLETE FOR S-IC ENGINE OUT CONDITION. GIVES ADDED STRENGTH. • RECOMMENDED ABORT SEQUENCE (FROM ELEVENTH FLIGHT LIMITS SUBPANEL. DEC 20, 1967, AND MEETING AT MSFC, FEB 5, 1968) PRESENTED TO CREW SAFETY PANEL AND FLIGHT MECHANICS PANEL FEB 15, 1968.	• PANEL POSITION TO BE PRESENTED TO VEHICLE MANAGER MARCH 15, 1968	STAPP/I-V-E HAGOOD / R-AERO-F#	TO BE DETERMINED
7	• ASSURE NO LEAKAGE OF ANY FLUIDS FROM SPACECRAFT INTO IU/S-IVB.	• SCHEDULE DELAY OR VEHICLE LOSS.	• MSC ELIMINATE LEAKAGE OF SPACECRAFT HYPERGOLS. • MSFC PROTECT LAUNCH VEHICLE FROM HYPERGOL LEAKAGE.	• PROTECTIVE CURTAINS AND WATER DELUGE WILL NOT BE USED ON AS-502 PER APO DIRECTION. • AS-204 UTILIZED CURTAINS & WATER DELUGE SYSTEM (P&VE DETERMINED DELUGE INADEQUATE). • PROTECTION FOR AS-503 UNDETERMINED. • CREW SAFETY PANEL CONCLUDED MINIMUM HAZARD TO CREW AFTER LOADING DOES NOT WARRANT ADDITIONAL PROTECTION OR INSTRUMENTATION.	• REASSESS PROBLEM IN TERMS OF POTENTIAL HAZARD, MANNED REQUIREMENT & VEHICLE SAFETY.	HARBER/I-V-E	

POTENTIAL PROBLEMS
- EXCESSIVE TIME TO REPAIR SATURN V LAUNCH VEHICLE. (SMITH)
- S-II-1 AND S-II-2 LH2 TANK INSULATION FAILURES. (CHERBEK)
- S-II STAGE BATTERIES FAILED QUALIFICATION TEST. (GINN)
- MATERIAL CORROSION AT COMPLEX 39. (SMITH)
- MECHANICAL TOLERANCES OF STACKED SATURN V. (HARBER)
- SATURN V LAUNCH VEHICLE SYSTEM DESCRIPTION AND FUNCTIONAL SCHEMATIC DOCUMENT. (SMITH)
- ACCESS TO J-2 ENGINES AND S-IVB LH2 TANK ENTRANCE ON STACKED POSITION. (O. L. SMITH)
- S-IVB LOX FILL AND DRAIN VALVE PRESSURE SURGE PEAKS DUE TO INADVERDENT VALVE CLOSURE. (CHERBEK)

STATUS AS OF 14 MARCH 1968

DISPLAY 01

Figure 10. Critical problem display.

to establish basic responsibilities as well as the limits of responsibilities for the parties involved. Once established, the documentation became fixed and could not be altered unless all parties involved came to agreement on terms.

It was important to establish the interface aspects at the beginning of the Saturn V Program, with collaboration of appropriate Inter-Center Coordination Panels, working groups within MSFC, contractor advice, and a strong input from the R&DO labs at MSFC.[20] Thus, if a contractor originated an Engineering Change Proposal (ECP) against the current configuration, he knew in advance the interface impact, since the interface documents were already drawn up, noting the potential downstream impact of the upstream change in question. The contractor had the opportunity to coordinate possible changes ahead of time, by notifying related personnel of the time of the change and its ramifications.

Inevitably, difficulties often cropped up during the process of interfacing various stages of the launch vehicle, spacecraft, the various hardware facilities, and related equipment and systems. So it was that, in order to maintain configuration control, a group of Inter-Center Coordination Panels was established to resolve the interface problems. Technical personnel were appointed from the centers and from other NASA agencies as well. The formal communications media between panel members involved the Interface Control Documents, divided into two levels: Level A documented technical interfaces between the centers and Level B did the same for end items supplied by the NASA contractors. If the change concerned a single stage and involved no other interfaces, then the proposal could go through a change board at the Project level at MSFC. If the change affected the interface with another "end item," it had to go to the program level (Level B). If the change affected the program of a different NASA center, it was necessary to go through the Inter-Center Coordination Panel to reach a decision (Level A). In situations where the Inter-Center Coordination Panel could not reach a decision, an executive group, the Panel Review Board (PRB), supervised and adjudicated the issues as necessary. The PRB was chaired by the Apollo Program Director at NASA Headquarters, and channeled its decisions back through the appropriate centers and program offices.[21]

Even after a decision to proceed on an engineering change was reached, it was necessary to relay all the appropriate change information to all areas that might be affected and make sure that the new guidelines were followed. In order to make sure that the configuration of the launch vehicle remained consistent, it was important to utilize effective configuration control. Richard G. Smith, one of Rudolph's successors as the Saturn V Program Manager,

remarked that "configuration management in some form is necessary in order to control technical changes and weigh them against cost and schedule impact." As a technique used in aerospace research and development (R& D) for several years, it reached its zenith in the 375-series manuals issued by the Air Force. NASA used a simplified version that was very effective, with control boards at each level of management. Their distinctive asset was that they operated so as to delegate the developmental effort in a very effective way at the lowest level possible, and made certain that every aspect of R& D activities and engineering design changes were properly monitored and evaluated from the standpoint of technical, schedule, and financial impact.[22]

Management at MSFC regarded configuration management under five basic functions. First, the idea was to make sure that the contractors adhered to the requisite procedures and disciplines in drawing room operations. Second, during manufacture, it was necessary to assure that design intentions were carried through. Third, there should be approval for mandatory changes only. Fourth, there was the need to know exactly the configuration delivered to the launch site, down to the most minute detail. Fifth, there had to be "traceability"--the capacity to trace failures in the hardware and materials down to the point of origin. Over a period of years, the management team at MSFC learned to approach these goals with some degree of caution. It could be very expensive, and caution had to be taken not to "overdo" in setting up the guidelines, so as to apply the goals wisely in regards to prime contractors and their subcontractors. Management had to constantly ask if too little or too much was being done; it had to keep close watch on the costs; it had to ask if the information coming out was really worthwhile and if it was being used.[23] The principles of configuration control were praised by Eberhard Rees, who remarked that they were "extremely fruitful judged against the enormous expense of the program and the dire consequences of failure." But he added a note of warning in terms of their application to other endeavors. "At a corresponding level of execution with more limited funds, it could have been prohibitively expensive."[24]

Within MSFC itself, there were a number of "working groups," that originated early in the Saturn Program to cope with various development problems that had cropped up, and they became the acknowledged organizations to work on the various interface problems concerning Huntsville's work on Saturn. The working groups were originally created in 1960 by Oswald Lange, who at that time headed the Saturn Systems Office. As he explained it, "The Working Groups have been formed to make available the experience of MSFC and contractor representatives toward the solution of stage interface and system problems." The idea was not to de-emphasize the responsibilities of other MSFC organizations or those of the contractor, but to provide a mode of

fast reaction for monitoring special areas and making informed, incisive recommendations through appropriate channels. The number of such working groups varied from time to time, with each group chaired by a senior technical authority from one of the laboratories, and a membership including representatives from the appropriate Program Offices. Their recommendations were channeled through the Program Office Configuration Control Boards.

The paperwork generated by all of these elements--Headquarters, Centers, contractors, and subcontractors--began to reach unmanageable proportions. The Saturn V Program Office attempted to keep the volume down, and to establish a level of priority for key documents. In other words, which instructions took precedence over others? It took several weeks to set up guidelines and levels of authority, but still the problem remained as to clarifying the new hierarchy of documentation. In an elegant solution, the Program Control Office prepared a master chart for the Program Control Center on which each of the key documents was displayed with appropriate lines of authority. With the master chart complete, notebook sized copies were available for distribution and reference (Figs. 11 and 12).[25]

MEETINGS AND REVIEWS

In order to gauge the status of the program and to assess its progress, hundreds of MSFC personnel engaged in various levels of daily, weekly, and monthly staff meetings. Although informal contact between Saturn V Program Office personnel and contractor personnel occurred on a day-to-day basis, in addition to recurring visits to contractor plants, the formal get-together was the format known as the Contractor Quarterly Project Review, which was begun in late 1964. In these meetings, top contractor and MSFC managers reviewed not only the technical status of the project, but also the management status of the project. In the meantime, the Saturn V Program Manager's Office customarily held various staff meetings with each of the Project Managers in Huntsville and also conducted a more elaborate monthly Saturn V Program Review with all of the Project Offices involved. These sessions, begun early in 1965, kept the Program Manager fully informed on a periodic basis and provided an additional forum to cope with interrelated problems. Moreover, it helped to generate information for the top-level Management Council meetings for the Office of Manned Space Flight, convened by the Associate Administrator at NASA Headquarters each month, or as required. For these meetings, the Program Managers and other designated personnel

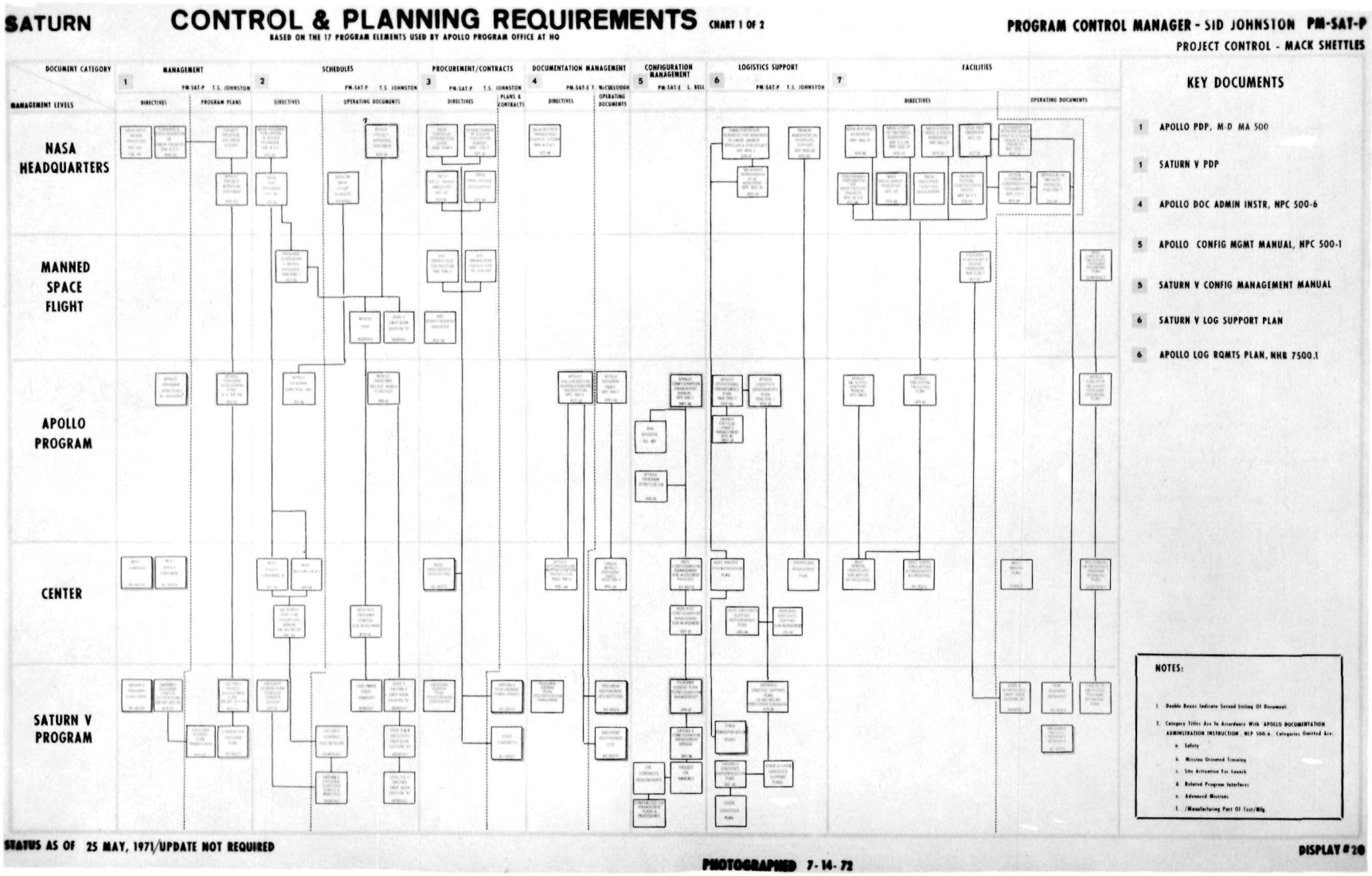


Figure 11. Control and planning documents, chart 1.

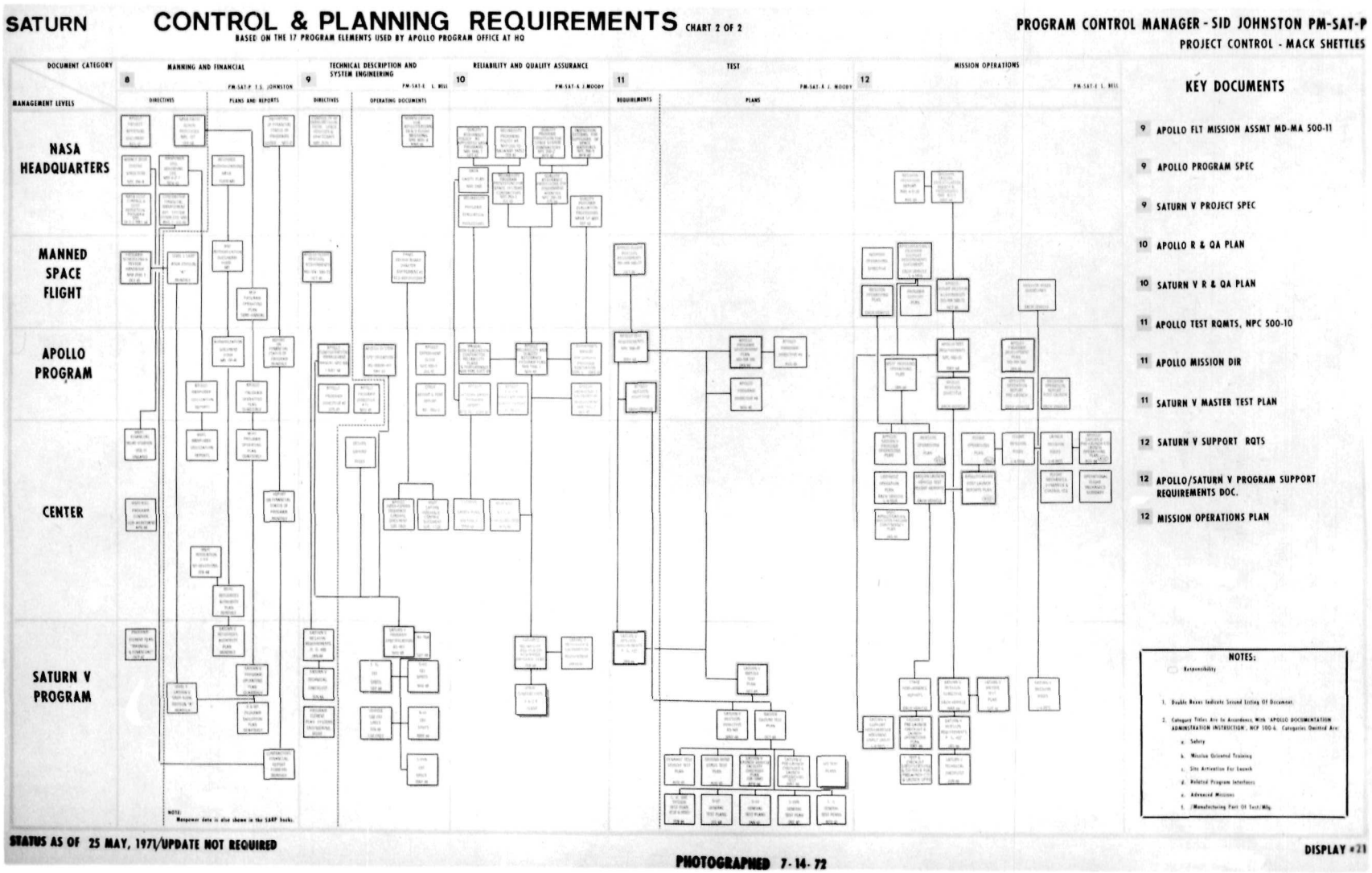


Figure 12. Control and planning documents, chart 2.

accompanied the Center Director and participated in analyzing problems and progress, while at the same time receiving Headquarters information on policy changes and various program directives. As a frequent participant on these occasions, Eberhard Rees summed up the usual format as follows[26]:

1. Where did the money go and can we manage within the allotted funds remaining?

2. What preplanned tasks have been accomplished and can we meet the projected schedule?

3. What are our major technical and programmatic problems and what previously unforeseen actions must be taken to overcome them?

4. What are our major motivational problems?

In addition, two other top-level meetings were customary in the Saturn Program, one within NASA management and one including the contractors. Once a year, OMSF conducted an annual Apollo/Saturn program review attended by the NASA Administrator, James Webb, and selected staff. The Center directors attended, and formal presentations were made by designated senior executives from within the Centers. These annual reviews gave the Administrator a comprehensive and critical analysis of contractor and program performance over the past year, with projections for the year ahead. Also, on occasion as required, George Mueller convened what he called the Apollo Executive Group. This group involved the chief executives of the contractors in the Apollo/Saturn Program. They met at various major contractor sites for briefings on what everybody else was doing, and visited each of the major NASA Centers. Mueller said that without the Apollo Executive Group, "we would not have been able to succeed -- it was one of the things that made it possible to suceed." All of the chief executives became more aware of the problems and possibilities, and felt more a part of the program. And it gave NASA and the Centers "top level interest and support."[27]

The Saturn Program used a technical review system to assure that development, design, fabrication, and test activities for each stage were properly evaluated. These reviews, such as Critical Design Reviews and Flight Readiness Reviews, were attended by senior technical experts and top management as appropriate (Fig. 13).

TYPICAL SATURN TECHNICAL REVIEW PROCESS

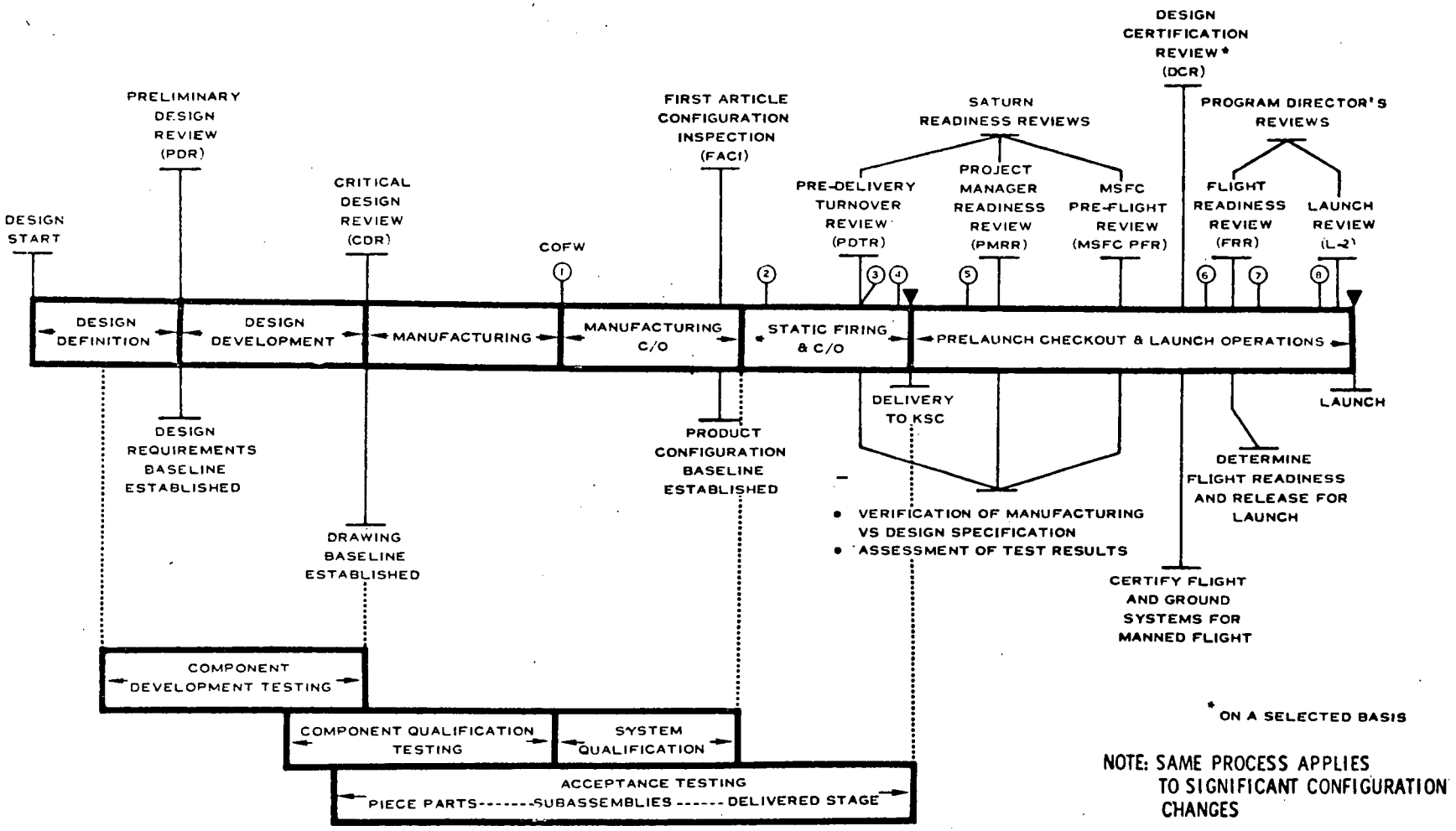


Figure 13. Saturn technical review process.

RELATIONSHIPS WITH THE CONTRACTOR

Aside from the various communications, visits to the contractor facilities, and quarterly reviews with the contractors, the Saturn V Program Office had immediate representation on the site in the form of the Resident Manager's Office (RMO). At each location, the on-site RMO operated as a "mirror image" of the respective Project Manager back in Huntsville. The RMO was directly responsible to him, and communicated with him on a day-by-day basis. The head of each RMO had a small staff of technical and contractual personnel from MSFC and, as the primary interface between MSFC and the contractor, exercised a reasonable amount of onsite authority when called for.[28]

Eberhard Rees admitted that the surveillance of contractor operations, as well as their management, was "somehwat sensitive from the point of view of the contractor." In many instances, contractors felt that they should be allowed to go their own ways, once the contract was signed. But Rees commented that this concept of loose reins on the contractor had not always worked out too well, from the MSFC point of view. "Consequently," he advised, "it became clear that close and continuous surveillance of the contractor operation was required on an almost day-to-day basis." The extent of the surveillance was proportional to the subtleties and problems of the program, its relative position in relation to existing state-of-the-art, and the extent of expertise possessed by the particular Government agency involved. Reaction to this aspect of Government monitoring was not favorable at first, but eventually this "penetration and monitoring" crystallized into the oft repeated phrase, the "Government-industry team." The concept of contractor penetration was an important one, involving the contractor's relationship with his own subcontractors, and eventually became a very successful concept, involving all personnel in the program. The key to this aspect, Rees said, was the implementation of the RMO concept in the plants run by the contractors.

Since the role of the RMO was to expedite decisions, he had specialized assistance in contract administration and technical engineering, supplied from the Center's parent organizations. This small cadre of specialists was "to assure that project management interests were advanced and that decisions were made and implemented within the designated scope of authority of the resident group." With the backing of his staff, guidelines supplied to the RMO allowed him to make certain on the spot decisions, including the authority to commit parent offices and/or functions of the Center. "This resident element proved to be a most important link between government and contractor activities

in the management of large programs." In Rees' opinion, the process of project management was definitely accelerated as a result of this on-site authority, providing a "dynamic interface" between MSFC and the contractor. As he described the functions of the RMO[29]:

> "Essentially contrived to focus specialized management attention on a day-to-day basis, it also provided a mechanism for tempering the varying emphasis on government project and functional groups and in the contractor organization. For example, the technical functions tend to strive primarily toward perfection to a degree possible inhibiting adequate attention to manufacturing and launch schedules or cost. The contractor could well be oriented toward schedule, costs and profits whereas the project manager might weigh his concern more heavily on schedule and costs. Through the offices of the resident manager, an automatic system of checks and balances developed to the end that each consideration received its appropriate share of attention." (See Figure 14.)

One of the most interesting aspects of MSFC and contractor relations was the concept of "contractor penetration," as exemplified by the RMO approach. In terms of affecting even managerial organization of the contractors, NASA could exert considerable influence in influencing technical decisions. General Samuel C. Phillips, who directed the Apollo Program Office at NASA Headquarters, revealed this influence during one of the Program Review sessions, held at NASA Headquarters in 1964. He noted that various contractors had strengthened their organizations during the preceding year, "either on their own or due to appropriate influence by NASA."[30]

Phillips' comment on the use of "appropriate influences" was something of an understatement since MSFC could, and did, exert a considerable amount of muscle in literally forcing contractors to change their mode of operations. In 1963, the development of the S-IVB stage reflected this initiative on the part of MSFC management. An interesting aspect of the S-IVB was its dual role, as the second stage of the Saturn IB vehicle and as the third stage of the Saturn V. This duality posed something of a problem of interfacing for the S-IVB prime contractor -- the Douglas Aircraft Company. As discussant for the S-IVB project during the 1964 program review, Lee James pointed out that MSFC management wanted to make sure that Douglas did "not see two faces at Marshall. It is important they see only one." So, as far as the contractor was concerned, the Saturn IB/S-IVB Manager acted as deputy to the Saturn V/S-IVB Stage Manager, placing basic responsibility in the Saturn V Program Office.[31]

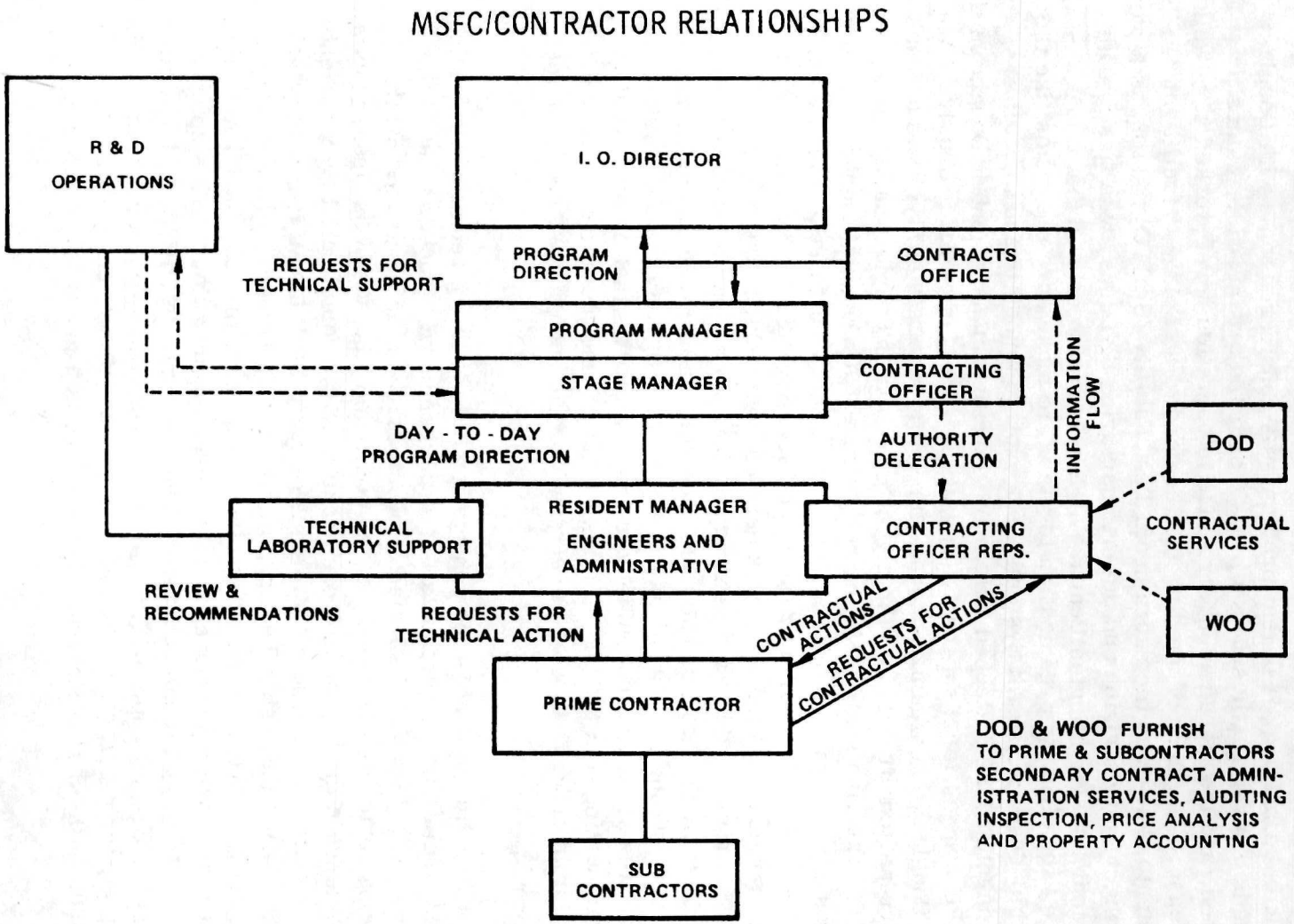


Figure 14. MSFC/contractor relationships.

During the course of his presentation, Lee James spoke on the subject of "Saturn I/IB Launch Vehicles and Related Facilities," in which he noted that management constituted a "major part of the problem." Moreover, he continued, "a major part of that problem was considered to be with Douglas." Douglas had never really set up a project oriented organization, James explained, and the management structure in operation never worked very well in any case. The crux of the difficulty seemed to be Douglas' facility at Sacramento, known as the Sacramento Test Facility (SACTO), set up as a part of the engineering division and the manufacturing divisions, with ties to both Santa Monica and Huntington Beach. As a result, James said that there was no place "to pull their organization together" to make sure programs like the Battleship Test and the All Systems Test evolved smoothly and logically. Management at MSFC stepped in to make sure that management at Douglas met the MSFC concept for a successful operation. Lee James put it bluntly: "We forced Douglas to reorganize Sacramento into a separate entity." As a result SACTO reported directly into the higher echelons of Douglas management, and MSFC was also involved in the reassignment of Douglas' Deputy Director of the Saturn Program as the new Director of Sacramento Test Operations, a further benefit to the reorganization. In order for MSFC to operate from a stronger posture at Douglas, it was decided to strengthen the office of the Resident Manager and bring a new man to do the job. James said that over 90 applications for the position had been received, and he was pleased to report that "a very strong individual" had been chosen. In fact, the successful applicant was so eager to shoulder the responsibilities that he took a cut in salary amounting to $8,500. "I think we have found just the man we are looking for in order to give us the strength on the spot that we need," James concluded.[32]

The policy of contractor penetration did not imply relentless meddling in the internal affairs or organization of the company. Indeed, most of the pressure applied by MSFC seemed to occur early in the program. While monitoring obviously continued, it was conducted on a somewhat lesser scale. The problems in the beginning were peculiar to the complicated requirements of simply getting "cranked up" in terms of early R& D inputs into a new program like S-IVB Battleship Testing, where MSFC, Douglas, and Rocketdyne (the engine contractor) were all involved. As one approach, MSFC formulated a "start team" using personnel from all three organizations. This special group operated so as to coordinate and channel early activities, and proved to be a very successful approach in the S-IVB Program. As the program reached momentum, the contractor assumed more responsibility on its own. "We also recognized in the S-IVB Program that Douglas is a major manufacturing

organization and once they get rolling, they are a good organization," said James emphatically. "Our problem always is on the initial stages. We have made a major effort to concentrate getting the first stage out the door, knowing we can trust a contractor like Douglas to follow on with the succeeding stages."[33]

Getting the contractor's initial stage out the door, however, did not always signify smooth sailing ahead. The S-II second stage of the Saturn V, manufactured by North American, became a severe problem for the Apollo/Saturn Program in the mid-sixties. A dramatic indication of the S-II difficulties occurred on September 29, 1965, when the S-II-S/D (structures/dynamic test stage) ruptured and fell apart during a loading test at North American's plant in Seal Beach, California.[34] This meant a serious delay in testing, and MSFC's dynamic test program at Huntsville was recycled to use the S-II-T (static test firing stage) after it had completed test firing at NASA's Mississippi Test Facility (MTF). Reviewing the problems during the annual program review at Headquarters, General O'Connor noted managerial and technical shortcomings at North American and said that MSFC had "caused changes to be made in management; some people have been moved." In spite of help from the R&DO labs at MSFC, there were continuing problems in welding, inspection, insulation, and component qualification, and the first S-II flight stage was more than 3 months behind schedule. "It is my opinion that program management at North American is perhaps the principal shortcoming of the entire S-II program," O'Connor said.[35]

During the spring of 1966, the S-II-T stage ran through several successful static firing tests at MTF before disaster struck again. This time, the stage ruptured and exploded during a pressure test on May 27, injuring several technicians.[36] The test program once more had to be readjusted, with loss of time and money, and the first flight stage, S-II-1, was sent to MTF for careful static test firing. MSFC personnel found numerous faults in the stage, as well as other stages. The second flight stage, S-II-2, had gone through manufacturing, but had to be sent back for numerous modifications and fixes. MSFC organized special "Tiger Teams" and dispatched them to Seal Beach for manufacturing aid and to MTF to assist in the static firing operations. Summing up the trials and tribulations of the S-II stages, General Phillips remarked, "the performance of the contractor has not measured up to the minimum requirements of this program."[37]

The problem of the S-II presented some difficult management challenges for the Saturn V Program Office. Arthur Rudolph concluded that the program had been badly starved for funds and began massive infusions of dollars into the S-II project for overtime, increased manpower, more R&D, and whatever was

necessary. Many observers at MSFC commented that the S-II had so many difficulties because it was pushing the state-of-the-art in terms of size, materials, welding, and insulation for such a large stage using liquid oxygen and liquid hydrogen as propellants. The S-II also got caught in the web of problems related to the Apollo payload, which had gotten heavier, and the weight-saving change orders on the S-II created difficulties in fabrication and manufacturing.[38] Management at MSFC had foreseen some of the problems, but they proved to be more complex than anticipated. There was also disagreement within Rudolph's Program Office, with the Project Manager claiming adequate progress before the troubles began to snowball, and the Program Control Office claiming that there were danger signs already evident.[39] Once the S-II got into deep trouble, reaction was swift and visible, especially in the form of the "Tiger Teams" at manufacturing and test sites. The program finally got back on track, with Government and contractor cooperation, and the S-II performed splendidly in every launch of the Saturn V vehicle, except for a problem on S-II-2 involving an ASI line and engine cross-wiring. Even this flight was beneficial, however, in that it demonstrated the S-II could meet mission requirements with two engines out.

It was obvious that the technique of "contractor penetration" in order to maintain high visibility generated some very thorny issues in Government/contractor relations. But MSFC nevertheless continued to feel that industry had a strong inclination to take control of the job and attendant funding, and pursue the job with a minimum of Government intervention. In the opinion of MSFC management, this allowed too much opportunity for slippage and problems of other sorts. On the other hand, vigorous contractor penetration reduced these program difficulties, and, in the long run, the contractors seemed inclined to accept the penetration as a mutually useful aspect of completing a successful program. "The restiveness that stemmed from such close control was gradually dissipated very early in the Apollo Program as the benefits accruing from the industry-Government team approach was revealed," concluded Eberhard Rees.[40]

TYPES OF CONTRACTS

Realizing the relationship between contractor motivation and success, the Saturn V Program Office implemented general NASA policy regarding contract incentives as a means of encouraging the contractor to perform at the highest possible level of endeavor. The original contracts were mainly the cost plus fixed fee (CPFF) type which were useful in the early phases of the

Apollo Program when management had to deal with a program containing many unknown factors, and close pricing was too uncertain. After the R& D phase was well in hand and the unknowns were worked out, it became possible to adapt incentive or award fee provisions in all Saturn contracts except the S-II stage contract. The S-II contract eventually had limited award fee provisions for management performance. The contracts for the Lunar Roving Vehicle and the Instrument Unit were cost plus incentive fee (CPIF) from their initiation. The remaining contracts were changed from cost plus fixed fee to cost plus incentive fee in the 1966 time frame.

The CPIF contracts were established in two portions. First, there was a comparatively modest base fee, and secondly there was a segment of payments scaled to incentives. These scaled incentive fees were awarded in proportion to the contractor's success in meeting time schedules, cost allowances, and performance ranges. The incentive fee type of contract was judged to be most successful in cases involving hardware contracts where schedules, costs, and major milestone were fairly well established. The Saturn V Program Office considered the CPIF approach a very successful alternative to CPFF contracts, since they encouraged the contractor to meet commitments on hardware delivery and contributed to mission success.[41]

RELIABILITY AND QUALITY CONTROL

Within the Saturn V Program Office, as in other MSFC operations, management paid special attention to the areas of reliability and quality control. Viewing reliability as a significant element of basic design technique, the project offices continued relevant techniques for judging the design of subsystems, components, and parts, as well as the overall stage design. This approach included techniques to evaluate the necessity for redundancy, criticality of numbers, and failure mode and effects analysis. Management also pursued an exceedingly active qualification test program, exposing components and subsystems to simulated flight loads under environmental conditions. This was a major contributive factor to the success of the Apollo/Saturn Program, but it was also expensive. The hardware itself was quite costly, and the rigorous testing of such a large portion of it meant that a lot of the hardware could not be released for duty as flight hardware. In some cases where funds were particularly tight, qualification tests were conducted at a reduced level, followed by intensive and exhaustive data analyses to extrapolate performance figures

through various regimes. The object here was to be able to use these hardware units on actual missions later on. In such instances, it was necessary to exercise special care not to overstress these future flight components, and to be very careful in extrapolating data so as to avoid risks during the actual missions.[42]

The problem of quality control was further affected by reliance on the Department of Defense, who exercised quality control management in some of the contractor plants. In the mid-sixties, MSFC made an effort to increase its own quality control programs, particularly in the inspection of incoming vendor products as supplied to the prime contractors. Over a period of time, the prime contractors themselves increased their vendor surveillance as part of the quality control objective. Douglas, for example, evolved its own Approved Parts List, and parts not listed were unacceptable in design specifications submitted by prospective vendors. Basic guidelines for the list came from MSFC documents, buttressed by information from the military, industry sources, Douglas' own experience, and substantiated by operational and test data in the course of the program. Candidates for the Approved Parts List included such things as bearings, fasteners, switches, relays, transformers, wire and cables, capacitors, resistors, semiconductors, and fluid fittings. Among the tangle of parts required to make a rocket work, the pipes and tubing with their respective connections were expected to operate under extreme adversities of cryogenic shocks, low density gasses, and added variables of wide fluctuation of temperatures and high intensities of vibration. It all had to be flight-weight and it all had to have the impramatur of the Approved Parts List.[43]

In the meantime, the Saturn V Program Office continued to monitor the activities of its own prime contractors, stepping in when necessary to advise changes that were deemed necessary. One such instance occurred in July 1964, when one of the weldments of the S-IVB stage failed and the consequent rupture of the tankage caused the loss of the entire Structural Test Stage. As a result of this incident, MSFC "caused Douglas to go into TIG welding with the higher heat input than the MIG welding that they were using in certain areas." Following the change, MSFC technical personnel reported better reliability quotients, and approved Douglas' revision of weld inspection procedures, which MSFC judged to have been somewhat weak.[44]

In the area of reliability and quality control, the project managers found that they had to exercise considerable diplomatic tact, assuring that the contractor had sufficient leeway to develop valid concepts without overdoing the design. "It is in the nature of experts that they become beguiled by intriguing technological problems," warned Eberhard Rees, and such beguilement could

lead to the pursuit of reliability and performance parameters to excess. Such an approach was sometimes tolerable in industry, in the interest of better products for competition, but not in the space program. In the latter instance, it was necessary to be constantly on guard against losing simplicity -- something that was easy to do in the early stages of a program that was complex, large, and pressed by tight schedules. "Even when weighed in the balance against sacrifice of performance, design simplicity should be strongly favored," Rees recommended. Reduced to the simplest paradigm, more components and higher performance parameters often increased the prospects for failure. Summarizing the problem, Rees noted that "Project Management has here a rather complicated task of putting the brakes on these tendencies without discouraging development of new technology and with it of highly inventive people." Rudolph himself was adamant about this point, and put it even more succinctly: "Make it simple, make it simple, make it simple!"[45]

In the quest for high performance, reliability, and quality control, incentivized contracts constituted only one of a number of motivational approaches. Several other techniques were employed by MSFC, including cash awards and special recognition for quality control, cost reduction, and other activities. At MSFC, the Saturn V Program Office cooperated with the Manned Flight Awareness Office in a program to inform and remind all workers in the Apollo/Saturn Program about the criticality of the activity and the need for individual effort for success. By means of awards and recognition programs, the Manned Flight Awareness concept became an effective incentive technique. The prime contractors also conducted special incentive programs, in collaboration with the Project Managers and RMO personnel. North American's program was known as PRIDE (Personal Responsibility in Daily Effort), and Douglas had its "V.I.P." campaign (Value in Performance). With MSFC's Manned Flight Awareness personnel, the contractors also participated in a program to make sure that vendors and subcontractors shipped critical spare hardware in special containers and boxes. These were marked with stickers and placards imprinted with reminders to handle with particular care, since they were important to the success of costly hardware and the astronauts whose lives depended on the integrity of the hardware.[46]

THE PROGRAM CONTROL CENTER

As a focus for decision-making, the Saturn V Program Office relied on a special facility known as the Program Control Center. The nature of the Saturn Program, with contractors and NASA facilities scattered coast to coast

presented a special management challenge as to the means of codifying all the information in order to make the correct managerial decisions. As explained by one of the Saturn V Program Office managers, it was "essential that we had some way of making sure that we had pulled together all the facets of the program into an integrated program with good visibility. And that, I would say, has been probably the main purpose of this Program Control Center -- to try to provide the Program Manager with that integrated visibility."[47]

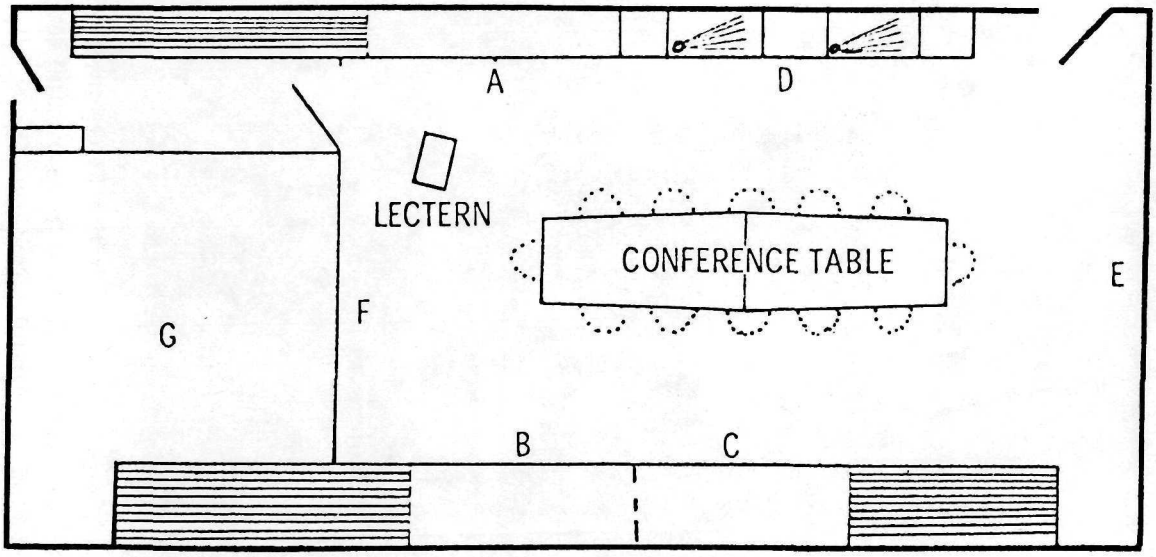
The archetype of the Program Control Center was probably the "Management Center", developed in 1956 for the use of Rear Admiral William F. Raborn, Jr., during the Polaris program. In the process of getting ideas for Raborn's Management Center room, his personnel visited the Air Force Ballistic Missile Division in Inglewood, California, and, interestingly, the ABMA operation in Huntsville. The Polaris Center was finally designed to avoid the look of a boardroom and was filled with 90 chairs facing a large glass motion picture/slide screen in the front, with numerous charts hung on the walls around the room. The idea was to provide maximum visual capability of Polaris events, and to serve as a briefing room.[48] As a management tool emphasizing visibility, The Boeing Company elaborated this concept during its Minuteman Missile Program for the Air Force. Beginning in 1959, a series of Boeing control rooms resulted in a style of visual presentations, by means of charts and audio-visual aids, intended to reduce the reams of management reports being used to monitor the progress of the program. The company activated such a control room at its S-IC (the Saturn V first stage) manufacturing facility at Michoud, near New Orleans, Louisiana, in 1964. In 1965, Boeing was awarded a contract by MSFC to develop an advanced control room management facility at Huntsville.[49] This became the Program Control Center (PCC) of Rudolph's Saturn V Program Office. Although the Marshall Center's PCC had something of the look of a boardroom about it, it became a highly utilized and active facility. The conference table in the center of the room seated up to 14 key principals, and the movable chairs around the edges of the room raised its capability to several dozen (Figs. 15 through 17).

In one way, the PCC epitomized the managerial concepts of "management by exception" and "single threading." The technique of management by exception was based on the premise that the Program Manager should keep his span of contracts within manageable limits, and Arthur Rudolph relied heavily on his Project Managers to carry the workload, vis-a-vis the contractors and various problems as they arose. "Within my Saturn V Program Office," Rudolph explained, "each Project Manager has wide latitude to exercise management actions just as long as these actions meet established technical performance requirements and schedule and budget constraints." Rudolph's control of the

Figure 15. Saturn Program Control Center, view to front. In the PCC, the Saturn V management team tracked a project that cost more than $2.5 million a day for 8 years and involved 100,000 people working for 12,500 companies in 47 states.

SATURN V PROGRAM CONTROL CENTER LAYOUT

CHARTS AND DIAGRAMS ARE A FORM OF COMMUNICATION PER SE, BUT THE FACILITIES MUST PROVIDE AN ENVIRONMENT FOR OPTIMUM EXCHANGE OF INFORMATION. THIS DIAGRAM ILLUSTRATES THE SATURN V FACILITY.



A- TOP LEVEL MASTER PROGRAM SCHEDULES.

B- SECOND LEVEL SUMMARY FLOW SCHEDULES.

C- TECHNICAL PERFORMANCE.

D- COST AND MANPOWER DATA.

E- SATURN V PERT SUMMARY NETWORK.

F- PROJECTION SCREENS FOR SLIDES, MOVIES, T V, AND VIEGRAPHS.

G- PROJECTION EQUIPMENT CONTAINING SLIDE, VIEWGRAPH, MOVIE PROJECTION, CLOSED CIRCUIT T V, AND TAPE RECORDER EQUIPMENT.

Figure 16. Saturn Program Control Center layout.

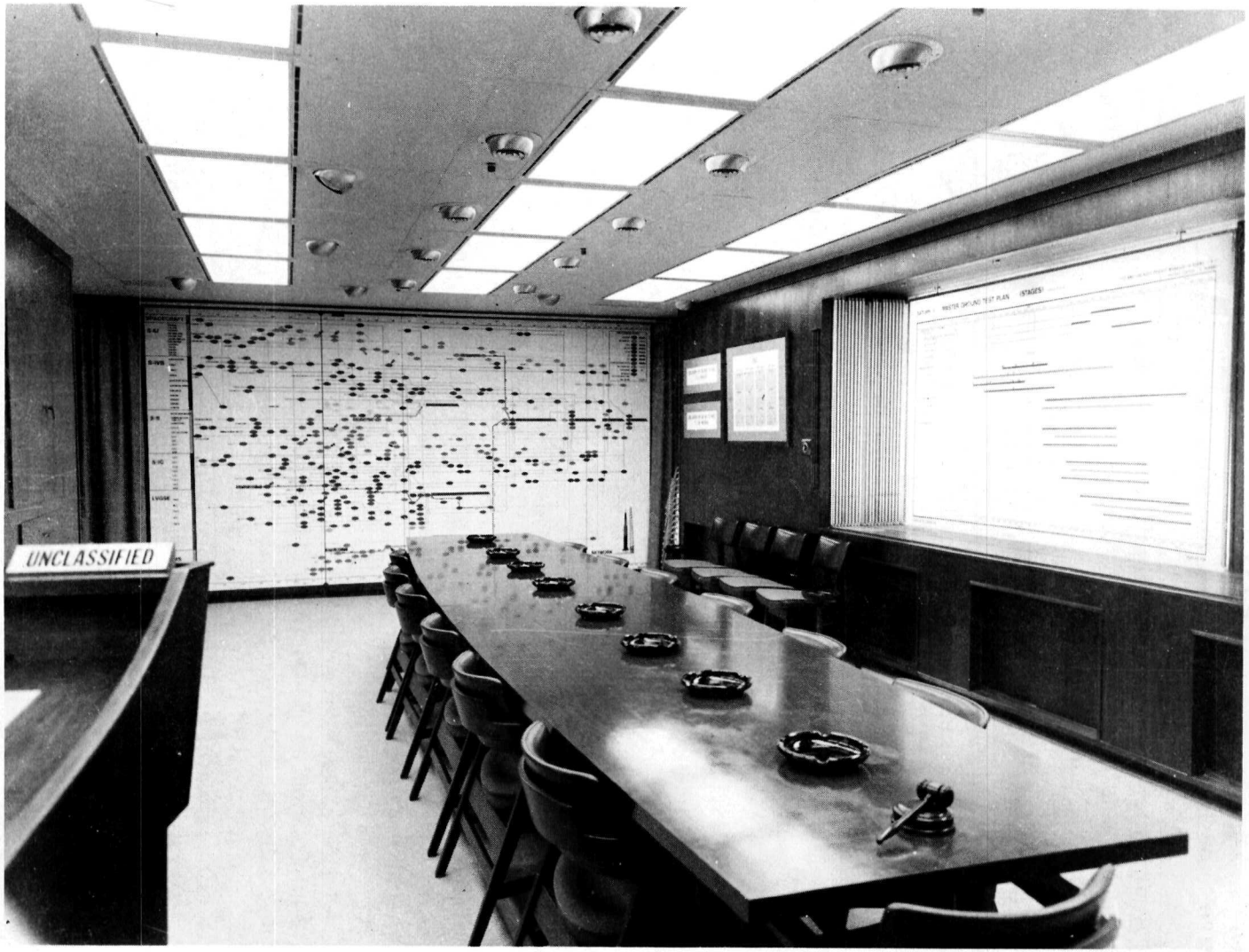


Figure 17. Saturn Program Control Center, view to rear.

Project Managers went just far enough to assure that performance, schedule, and budget guidelines were met, that interfaces were kept in repair, and that redundancy was eliminated. "This policy of management by exception has enabled us to operate effectively and efficiently and has given my people the incentive to perform to their fullest capabilities," he said.[50]

Within the framework, however, it was necessary to develop a means of singling out special problems for more detailed analysis, including probable program impact, and to know exactly who was responsible for monitoring and solving the problem. The concept of "single threading" provided graphic documentation, by way of charts, for tracing a problem down to a detailed position for assessment and probable course of action to resolve it (Fig. 18).[51] The means for such analysis was embodied in the data organized for viewing in the PCC. As such, the PCC was an arena for comprehensive displays for use by management -- a focal point for collection and presentation of information concerning the status of the Saturn V Program, and planned so as to provide displays for various levels of detail, permitting managers to identify the problem, begin action for resolution, and monitor the progress.

In reality, the PCC for the Saturn V Program Office was one of a network of such rooms, located in the Apollo Program Director's Office at Headquarters, at each of the three Apollo/Saturn NASA Centers (Kennedy, Marshall, and Houston), and each of the prime contractors, as well as MTF. Together, they allowed top management and other personnel to keep up with a myriad of activities, including logistics, astronaut training, scientific projects, selection of lunar landing sites, the world-wide tracking network, mission planning, and the mission itself. Each had the latest information and up-to-date displays for its appropriate job, including general Apollo/Saturn Program information as required, along with a sophisticated communications system to accelerate the decision-making process.[52]

The PCC provided two basic ways to display information: open wall displays and projected visual aids. The open wall displays were used to portray information that was updated and changed on a cyclical, day-to-day, or new problem basis. Most of the display charts were constructed so that they could be moved in and out of position on special horizontal tracks. They were marked by coded symbols so that the viewer could tell at a glance if a project was lagging, ahead of schedule, or currently on schedule. Both the Project Offices and the staff/functional offices submitted appropriate data and maintained liaison with PCC personnel throughout preparation and use of the display charts, and were responsible for having proper attendance in meetings where their display material was to be discussed (Figs. 19 and 20).

SATURN V PCC

Single Thread Concept

The illustration on this page shows "single-threading" of a hypothetical problem. Timely knowledge of the behind-schedule condition may be traced quickly to late delivery of hardware. This further traces through back-up information to a specific part. By following the "Single-Thread" through the behind-schedule or excepted items, the knowledgeable person at the stage office level can be contacted personally.

With the resulting information, a management decision can be made.

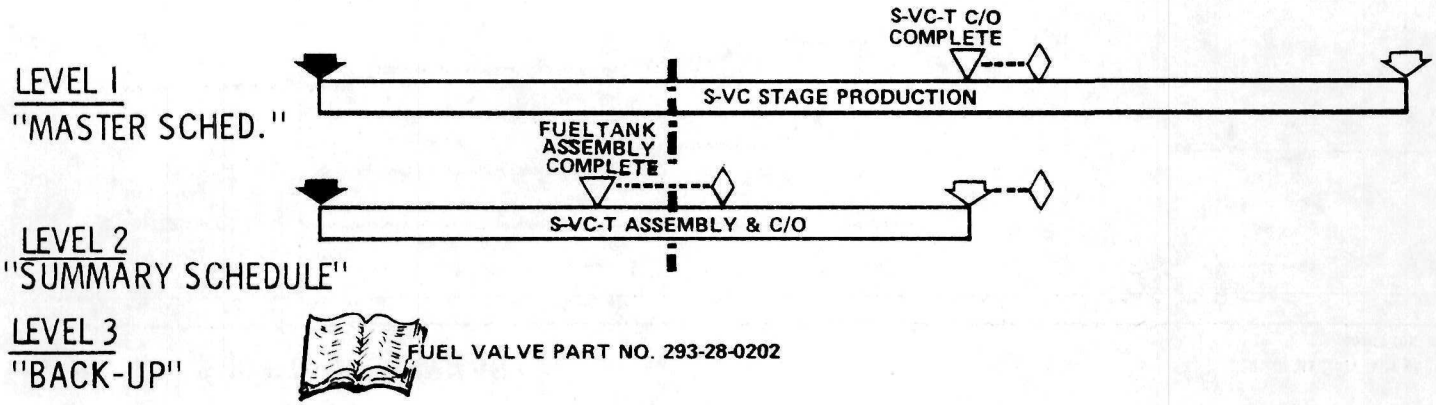


Figure 18. Single thread concept.

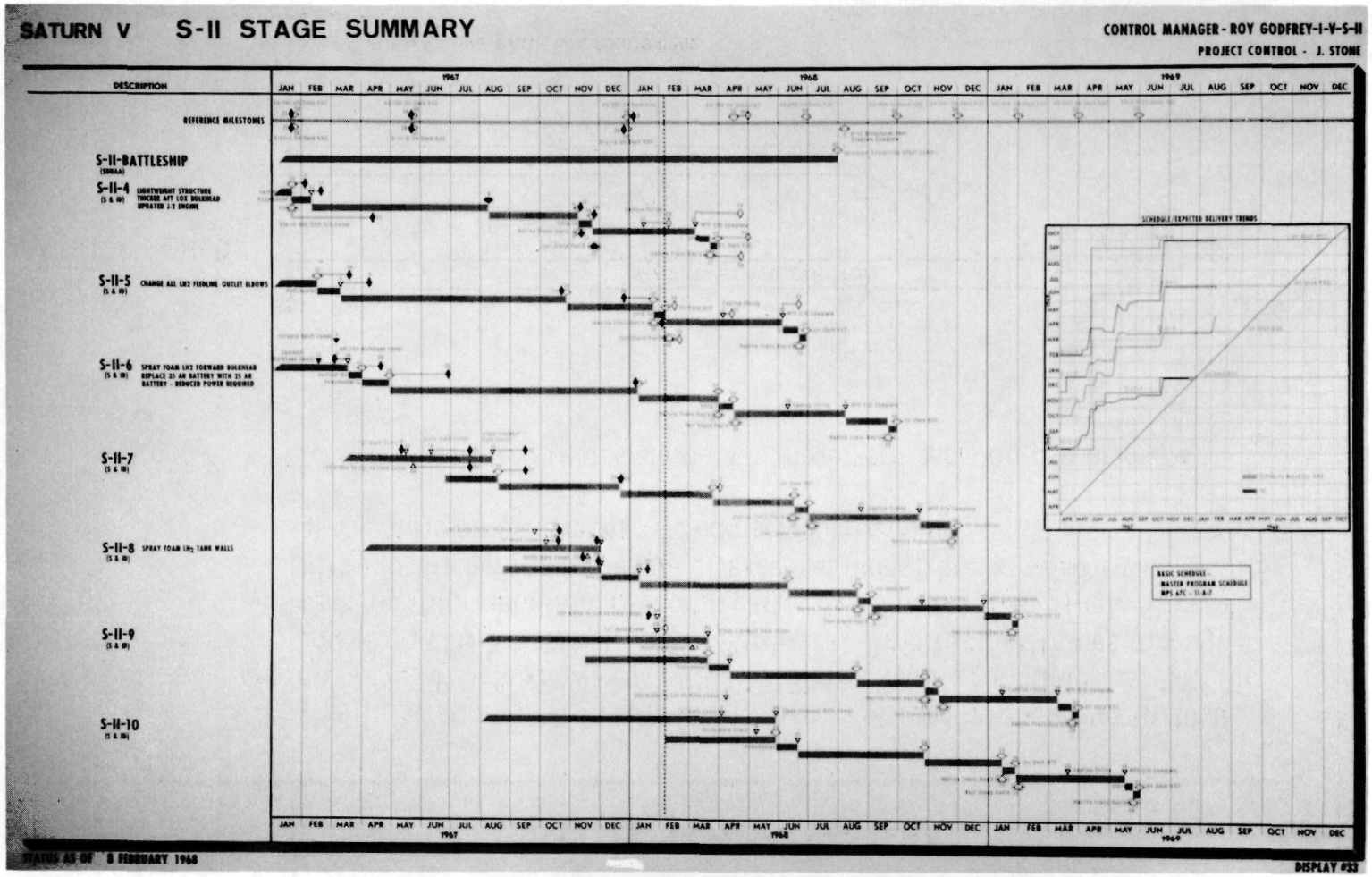
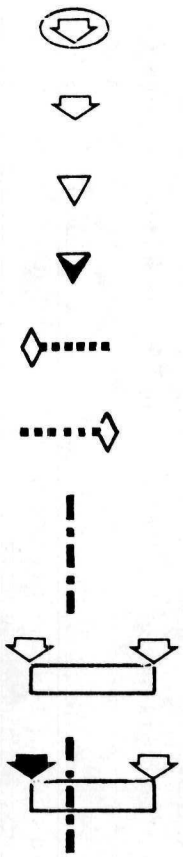


Figure 19. Typical PCC chart, prior to use of Xerox camera reproduction.

SATURN V PCC	Chart Symbols



Interface milestone

Major milestone - established by top management

Intermediate milestone - established by Project Office

Contract Delivery Date

Anticipated early completion

Anticipated late completion

Status as of

Scheduled time period

On schedule

Note: A filled-in symbol of any type denotes actual completion.

Figure 20. Standard chart symbols for all control centers.

An important aspect was that each display carried the name of the individual responsible for the data on view. If the Project Office representative could not answer questions, or supply additional information, the person to contact was immediately identifiable from the chart, and a quick phone call could get him -- or the information -- during the meeting. For example, some charts concerned items being covered by what MSFC called the Problem Resolution System. The data on view indicated the criticality of the problem, the specific hardware or operation involved, the originator of the data, the "Action Manager" coping with it, and its current status. Other charts showed aspects of costs, technical data (weight, performance, configuration management), and so on.

But always, Rudolph insisted on having a name associated with the charts. He wanted to work with a person, he said, not just an anonymous office. Backing up the charts was a comprehensive set of "management matrices" in notebooks, listing all individual counterparts, by name, for all major systems and subsystems of the hardware, in addition to all of the functional people. The matrix pages included MSFC counterparts for IO and R& DO, other Centers, and the contractors as well. To find out why a valve didn't work, the Saturn V Program Office could call each person responsible, and not waste time calling the wrong office or waiting for an office manager to decide who was competent to respond to a specific query.[53] Rudolph wanted a fast and accurate response to problems, and he usually got it (Fig. 21).

For a long time, the rear of the PCC was dominated by a huge PERT chart (Performance, Evaluation, and Reporting Technique). PERT was a sophisticated and complex computerized system, with inputs beginning, literally, at the tool bench. Technicians on the floors of contractor plants around the country monitored the progress of nearly all of the hardware items and translated the work into computer cards and tapes. Data for costs and schedules were also entered into the system. If a gas generator exhaust line under test in California was showing problems, how would this affect the static test schedule at MTF, and a scheduled launch from Cape Kennedy? What will be its cost impact? How will it affect other hardware? What do we do about it? Broken down into 800 major entries, summarizing 90,000 key events taking place around the country, PERT helped provide the answers (Fig. 22).[54]

The concept of the PERT network, like the PCC, received a strong impetus in the Polaris program in the mid-fifties.[55] During the early phases of the Saturn Program, MSFC management regarded PERT as a very successful effort. During a NASA Management Advisory Committee conference in 1964, von Braun said that PERT was the best source of information available on the

HARDWARE

SATURN/S&E/CONTRACTOR

SUB-SYSTEMS MANAGERS S&E DESIGNATED TECHNICAL PERSONS/CONTRACTOR COUNTERPARTS

* ESE
** MGSE

SATURN V PROJECT OFFICE	TITLE	SUB-SYSTEMS: STRUCTURES	PROPULSION	ELECTRICAL	INSTRUMENTATION	FLIGHT CONTROL	GUIDANCE	ENVIRONMENTAL CONTROL	STAGE PECULIAR GSE
S-IC PROJECT OFFICE	S-IC Subsystems Mgr.	C. Buist PM-SAT-C	D. Toles PM-SAT-C	R. Abraham PM-SAT-C	R. Abraham PM-SAT-C	C. Buist PM-SAT-C	None	D. Toles PM-SAT-C	I. Akbay PM-SAT-C
	S&E Designated Technical Persons	J. MacDonald S&E-ASTN-XSC	J. MacDonald S&E-ASTN-XSC	Billy Cagle S&E-ASTR-BV	Billy Cagle S&E-ASTR-BV	Billy Cagle S&E-ASTR-BV	None	J. MacDonald S&E-ASTN-XSC	J. MacDonald S&E-ASTN-XSC
	Contractor	P. Cox Boeing	P. Cox Boeing	Tom McGill Boeing	Tom McGill Boeing	P. Cox Boeing	None	P. Cox Boeing	P. Cox Boeing
S-II PROJECT OFFICE	S-II Subsystem Mgr	W. Warren PM-SAT-SII/SIVB	P. Bridwell PM-SAT-SII/SIVB	L. Guzinsky PM-SAT-SII/SIVB	L. Guzinsky PM-SAT-SII/SIVB	W. Warren PM-SAT-SII/SIVB	None	W. Warren PM-SAT-SII/SIVB	L. Guzinsky PM-SAT-SII/SIVB
	S&E Designated Technical Persons	R. Hunt S&E-ASTN-A	R. Zagrodzky S&E-ASTN-XSH	C. Glass S&E-ASTR-BV	C. Glass S&E-ASTR-BV	C. Glass S&E-ASTR-BV J. Sims S&E-AERO-P	None	R. Zagrodzky S&E-ASTN-XSH	H. Hill S&E-QUAL-EA R. Zagrodzky S&E-ASTN-XSH C. Glass S&E-ASTR-BV
	Contractor	W. Long NR/SD	J. Florey NR/SD	F. Knowlden NR/SD	F. Knowlden NR/SD	J. Florey NR/SD	None	J. Florey NR/SD	J. Florey NR/SD
S-IVB PROJECT OFFICE	SIVB Subsystem Mgr	W. Warren PM-SAT-SII/SIVB	P. Bridwell PM-SAT-SII/SIVB	J. Darsey PM-SAT-SII/SIVB	J. Darsey PM-SAT-SII/SIVB	W. Warren PM-SAT-SII/SIVB	None	W. Warren PM-SAT-SII/SIVB	L. Guzinsky PM-SAT-SII/SIVB
	S&E Designated Technical Persons	R. Hunt S&E-ASTN-A	R. Griner S&E-ASTN-XSJ	C. Glass S&E-ASTR-BV	C. Glass S&E-ASTR-BV	C. Glass S&E-ASTR-BV J. Sims S&E-AERO-P	None	R. Griner S&E-ASTN-XSJ	H. Hill S&E-QUAL-EA C. Glass S&E-ASTR-BV R. Griner S&E-ASTN-XSJ
	Contractor	R. Stewart MDAC	W. Kavasch MDAC	A. W. Rebarb MDAC	A. W. Rebarb MDAC	M. Plomer MDAC	None	M. Plomer MDAC	M. Plomer MDAC
S-IU PROJECT OFFICE	IU Subsystem Mgr.	J. Dickinson PM-SAT-IU	None	K. Byram PM-SAT-IU	N. Pearch PM-SAT-IU	T. McKay PM-SAT-IU	T. McKay PM-SAT-IU	J. Dickinson PM-SAT-IU	T. McKay PM-SAT-IU
	S&E Designated Technical Persons	J. MacDonald S&E-ASTN-XSC	None	D. Smitherman S&E-ASTR-BV	D. Smitherman S&E-ASTR-BV	D. Smitherman S&E-ASTR-BV	D. Smitherman S&E-ASTR-BV	J. MacDonald S&E-ASTN-XSC	F. Kelley S&E-ASTR-GS
	Contractor	O. McWithey IBM	None	J. Lundberg IBM	L. Murphy IBM	J. Lundberg IBM	J. Lundberg IBM	L. Murphy IBM	W. Sasiela Bendix J. Lundberg IBM

NOTE: LV/GSE does not have the same detailed function breakdown as the other stage offices; consequently, refer to Matrix 17 for S&E points of commitment and Matrix 20 for contractor counterparts.

Figure 21. Management matrix (typical).

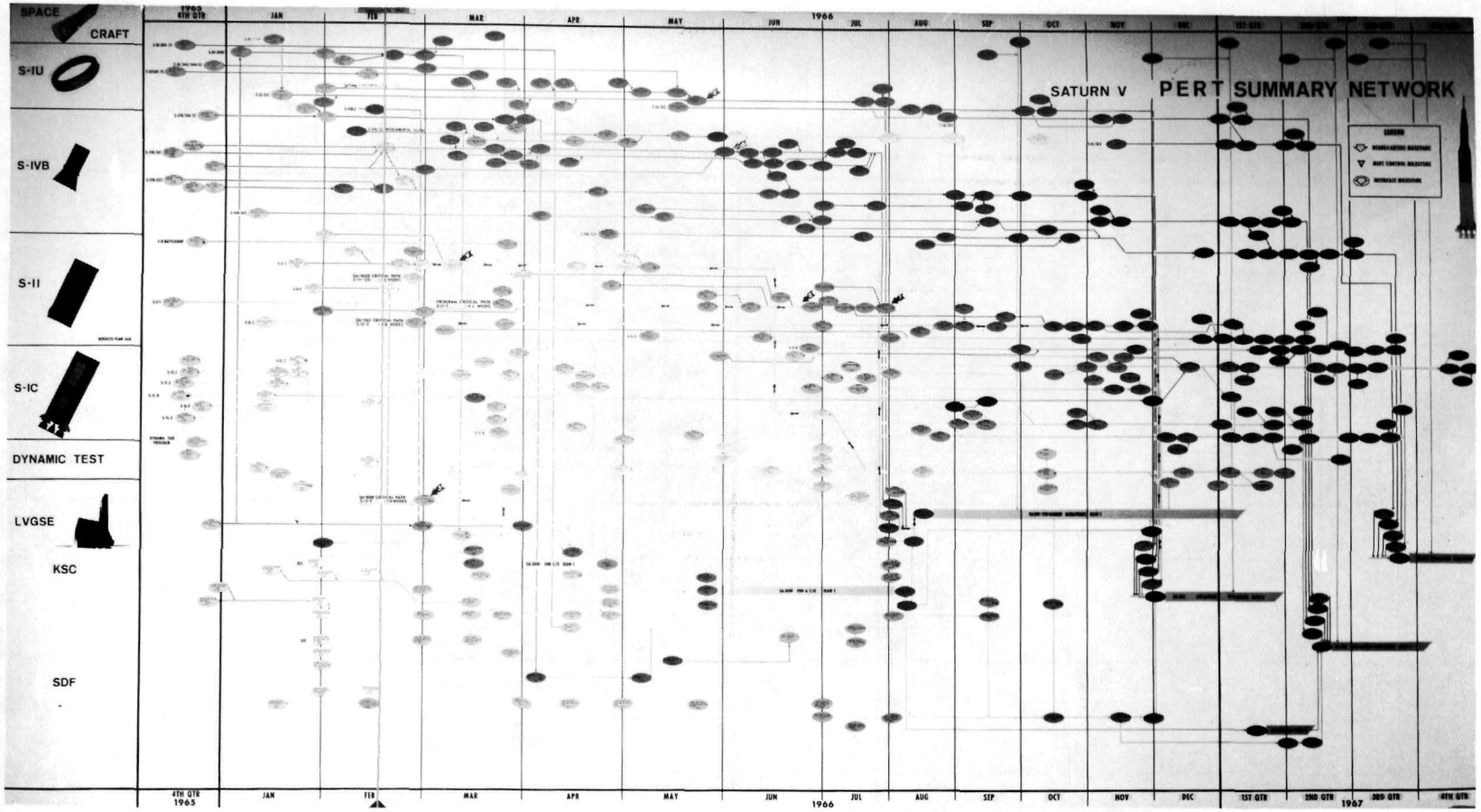


Figure 22. Saturn V PERT chart.

status of hardware programs. At the same time, the PERT network did not catch everything: a parts problem on Boeing's S-IC-T (test stage) had been missed. Still, MSFC managers in 1973 recalled PERT as one of the most useful management systems, even though the PERT network was phased out about the time of the launch of the first Saturn V vehicle (AS-501) in the winter of 1967. For one thing, it was tremendously expensive. Making the network perform adequately demanded a large number of people within NASA and from the contractor's special computer programs. "It has some use as a preliminary planning tool," said R. G. Smith, a Rudolph successor, "but when tens of thousands of events per stage are used, it is difficult to analyze, usually lagging in real time usefulness, and subject to manipulation to avoid exposure of real problems."[56]

The paraphernalia to serve PCC display requirements included slide projectors, viewgraphs, and motion-picutre projectors. The PCC used a pair of rear-projection glass screens at the head of the room, where a speaker's lectern was located. The lectern was equipped with an array of switches so that whoever was making a presentation could dim the lights, activate a remotely controlled slide projector, turn on the movie projector, or signal for a change of viewgraphs. The lectern also contained controls for tape recording if desired. All of this audio-visual equipment was housed in a permanent work area behind the glass screens. The wall charts were also backlighted, so that they would stand out for use while the lights were dimmed during audio-visual presentations. The size and complexity of the charts required a separate workroom nearby. This workroom contained all of the necessary materials for preparing the wall displays, including photographic and other reproduction equipment. Since the wall charts were constantly changing, reflecting the evaluation of the Saturn Program, PCC personnel shot a photo of each chart before it was updated or dismantled to make way for a new display and kept the photos in a special historical records file.

The reproductions of these wall charts played an important role in MSFC's inputs into Schedule and Review Procedure (SARP) reporting. SARP was a Headquarters requirement, "as the official method of documenting manned space flight program status as a basis for review and evaluation of total program effort." A compilation was submitted monthly to Headquarters, although a selected SARP compilation was prepared every Monday morning for reference use by key personnel in the Saturn V Program Office and other appropriate levels of Center management. In any case, the SARP reports represented the latest official status of the Saturn V Program as visible in the Program Control Center, and provided a very useful reference tool and visibility in reports to Headquarters.

The actual preparation of the SARP pages required some special attention. When new and updated charts were completed in the chartroom work area, personnel used a special Xerox copy camera to shoot a picture of the chart. The Xerox camera was set at a calculated focal point so that the information delineated on the 8 by 5 foot wall charts was precisely "shot down" to the 8.5 by 11 inch sheets used for the SARP reports. This required some experimentation on the original charts, choosing lettering that would still be legible in its reduced scale and choosing chart colors that would show up on the Xerox copy. This system, while appearing to be disarmingly simple, was the result of considerable trial and error and was judged to be highly successful. Reproducing the charts from standard photos was unwieldy and time consuming, as well as lacking in clarity. Redrawing all the charts on such a frequent basis was out of the question. The carefully planned and scaled Xerox camera copies afforded legible reference charts, literally within minutes (Fig. 23).

During launch operations and special activities, the PCC was linked to KSC and Houston by means of closed circuit television. Although conferences in the PCC were not televised by closed circuit (because of space limitations and technical problems), the communications arrangement permitted discussions in the PCC to be heard at NASA Headquarters and other Centers instantaneously. The ceiling of the PCC room was studded with extra-sensitive microphones, so that anyone at the conference table in Huntsville could interject a comment or respond without leaving his seat or waiting until a speaker somewhere else had finished. When a main speaker in Huntsville was making a presentation, an audience in Houston or Cape Kennedy could freely respond. In addition, conferees visually followed the presentation at other locations by means of viewgraphs supplied beforehand by the speaker. The viewgraphs were transmitted by Long Distance Xerox (LDX) system on a leased telephone circuit. Using a standard 8.5 by 11 inch size, the LDX line transmitted high-fidelity copies at the rate of about two copies per minute. After receipt at the other end, personnel used them to reproduce the numbered viewgraphs, shown in sequence as requested by the speaker. The fast response of the LDX system permitted up-to-the-minute documentation, and, if there was not time to prepare new viewgraphs, conferees at the other locations could be supplied with regular Xerox copies instead. The ability to exhange such material, whether viewgraphs, working drawings, or other documentation (such as SARP charts), meant that informed decision-making could be accomplished while the meeting was in progress. It was one of Rudolph's techniques that the viewgraphs themselves were rather extensive, in terms of words as well as diagrams, so that they could serve as minutes of these PCC conferences.[57]

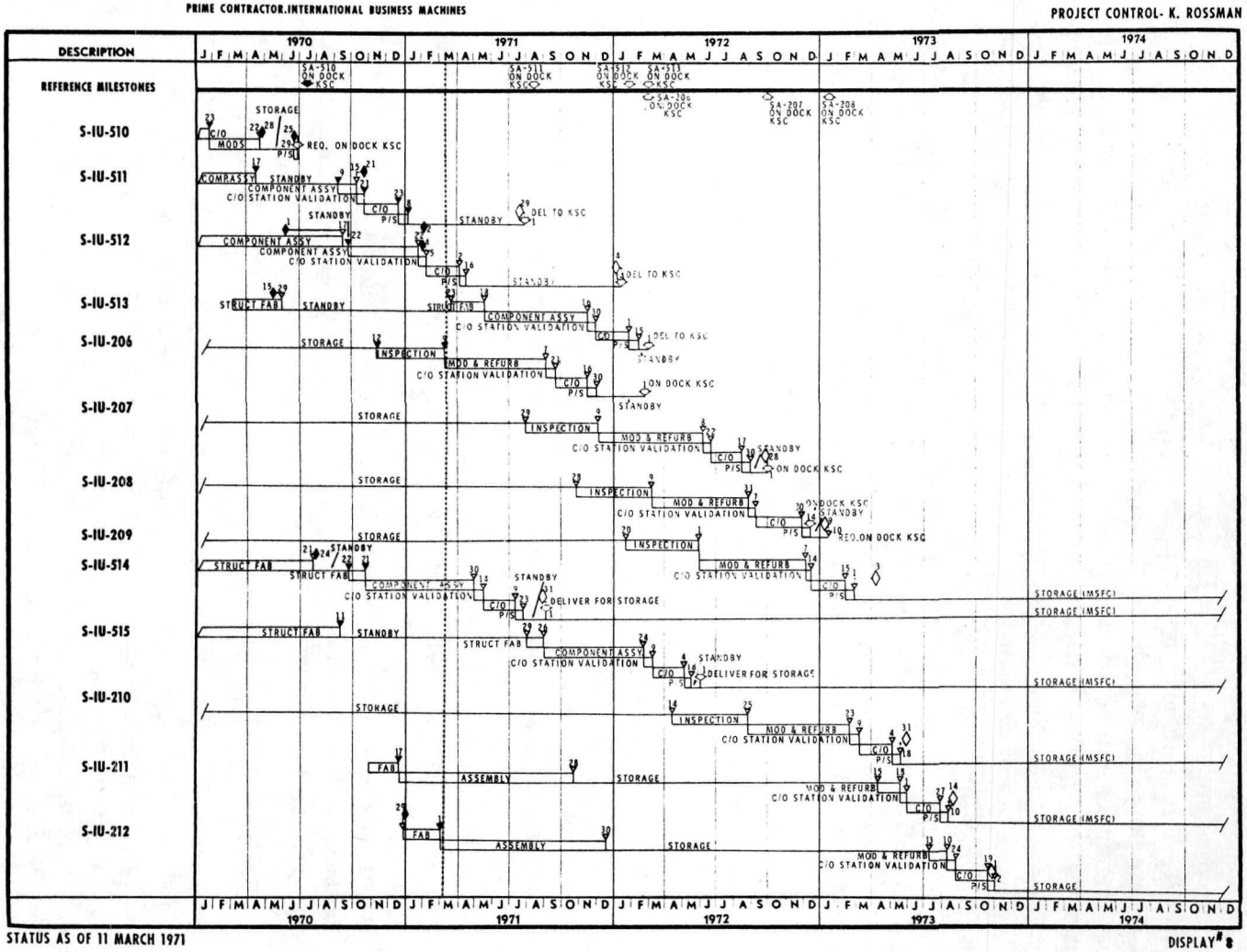


Figure 23. Typical PCC chart, formatted for Xerox camera reproduction.

SUMMARY AND CONCLUSIONS

James Webb, NASA Administrator from 1961-1968, warned that in large scale endeavors, such as the Apollo/Saturn program, managers needed to be especially flexible, since many "unpredictable difficulties" as well as many "unanticipated opportunities" would crop up. Many traditional management concepts, perforce, were not applicable, since the large scale endeavor simply was not a static situation. It was necessary for managers to have a sound foundation in basic management principles, but be able to work in an environment where the lines of communication crisscrossed, moved in unusual directions, and where the job did not always have an exact definition in the beginning. In the environment of the large-scale endeavor, the successful manager had to do more than understand the organizational framework backward and forward. He had to grasp the total dimensions of the effort and relate to his place in all of the elements comprising the task.[58] In this context, the style of successful aerospace managers was to avail themselves of existing fundamentals of management, whatever their source of origin, and raise them to a higher degree of refinement in complex aerospace activities involving high technology.[59] One sophisticated observer characterized NASA's managerial contributions as follows[60]:

> "To accomplish the moon landing within the time set by President Kennedy, Apollo's designers deliberately hewed to techniques that did not reach far beyond the state of the art in the early Sixties. The really significant fallout from the strains, traumas, and endless experimentation of Project Apollo has been of a sociological rather than a technological nature: techniques for directing the massed endeavors of scores of thousands of minds in a close-knit, mutually enhancive combination of government, university, and private industry.
>
> Apollo has spawned an intimate and potentially significant new sociology involving government and industry, an approach that appears to stand somewhere between the old arsenal concept favored by the Army and Navy and the newer Air Force concept that depends heavily upon private corporations to manage, develop, and build big systems. The NASA approach combines certain advantages of each, while enhancing the total abilities of both private and government organizations."

In terms of the Saturn Program, successful management was a blend of the decades of experience of the original von Braun team in Germany, management concepts from the Army, Navy, Air Force, and Government, and private industry. As the Saturn Program evolved at MSFC, the Army's arsenal concept was inherent in the R& DO arrangement, although its premier role was altered as a result of the 1963 reorganization. As the early SSO began to elaborate its relationships with prime contractors, Air Force concepts of configuration management became more conspicuous. Both the Army and the Air Force contributed key managerial personnel. Numerous Army officer executives left ABMA to join MSFC, including Lee James, who served at one time as the Saturn I/IB Program Manager, worked at NASA Headquarters, and later was head of the IO division. James replaced General O'Connor, who had returned to the Air Force. From NASA Headquarters, the concept of Mueller's GEM Boxes was a significant managerial technique in the Apollo/Saturn program, and MSFC elaborated its own concepts of working groups, management matrices, and the Program Control Center.[61]

From his vantage point as an active manager in the Army and NASA, and observer of Air Force management, Lee James paid special tribute to the R& DO labs, which gave MSFC "unusual depth." The labs were one of the outstanding aspects of MSFC management under von Braun. "It's hard to make them work in the government," James said. "That is a unique attribute."[62] Although von Braun emphasized the overriding authority of the program and project offices in their relationships with the labs,[63] their contact was not always unruffled. During a session with Headquarters executives in 1964, both Rees and von Braun agreed, "The project manager is definitely in the driver's seat on project management matters. R& DO provides technical knowledge in depth to solve the technical problems, but at the same time carefully avoiding any interference with contract management. The stage manager is the sole contact with the contractor." Reading the minutes of the meeting a few days later, one of the top level managers in the Saturn V Program Office expressed his frustrations in an astringent comment scribbled in the margin: "Wouldn't it be <u>good</u> if this were so! Top mgt. needs to say so in a policy statement and then enforce it."[64] The situation festered for several months, until von Braun issued a detailed directive to the heads of both IO and R& DO, in which the authority of IO (and the Saturn V Program Office) was asserted in very explicit terms.[65]

Although it is difficult to document, the relationships between IO and R& DO were often uneasy. As recalled by an observer from within the Saturn V Program Office, one form of managerial assertion was out-and-out harassment. A stage manager might call up a lab chief in R& DO and complain about the lack of activity or cooperation from the counterpart personnel in the labs.

Other methods included pointed reminders about directives from the Program Manager's Office, a claim to be acting at the behest of the Program Manager, the use of technical knowledge that others would hesitate to contradict, and outright exposure of deficiencies.[66]

The same techniques were also applied within the Saturn V Program Office, as the staff/functional managers (the GEM Boxes) jousted with the Stage Managers. It must be remembered that Rudolph considered his functional managers to have as much authority as his stage managers. This, incidentally, was unique to the Saturn V Program Office -- other program offices tended to allow the hardware managers greater authority. But Rudolph's arrangement was deemed necessary in order to maintain a sort of vertical control over the stage elements of the Saturn V, especially since the stage managers were sometimes considered to manifest something of a parochial attitude in regards to their own activities.[67] The role of the functional managers was spelled out in a PEP document[68]:

> "Establishment of managers for functional areas is an important management concept used in the Saturn V Program. These functional areas, e.g. Program Control, Systems Engineering, Test, may be considered as "vertical slices" of the vehicle which result in stages, or "hardware" items. The functional managers are responsible for planning, coordinating and directing their areas, insuring that a single thread of effort is carried from the highest level of Apollo management in Washington through the Center level and into the prime contractors."

The Saturn management concept consistently put a premium on visibility, epitomized by the Program Control Center in the Saturn V Program Office. James Webb, who prided himself in the development and exercise of managerial expertise, was amazed by its conceptual format and versatility. During a visit to MSFC in 1965, not long after the activation of the PCC, Webb was given a thorough briefing on the facility by Rudolph and Bill Sneed, who was head of the Program Control Office at the time. Following the briefing, Webb addressed a select group of MSFC personnel, and was still obviously kindled with enthusiasm for the PCC concept. "I saw here in the hour before you arrived," he exclaimed to his audience, "one of the most sophisticated forms of organized human effort that I have ever seen anywhere."[69] It was a special compliment to Huntsville's PCC that it became the model for NASA's Apollo Program Office in Washington, as well as for other Centers and prime contractors. Over a period of years, at Webb's behest, a stream of V.I.P.'s and key executives

from government and industry trouped through the PCC. The guests included George Schultze, director of the Bureau of the Budget; top military brass from the Pentagon, Great Britain's RAF, and other foreign nations; privileged managerial executives of the United States and abroad; and European space agencies like ELDO and ESRO. The Saturn V Program Office also received inquiries by telephone and letter from a wide spectrum of sources, including the famed design group of Raymond Loewy and Associates. At one time, a former member of the Polaris management team went into the PCC and came away thoroughly impressed. "This chart room of yours is an amazing place," he said to Rudolph. "I used to think the ones we had in the Polaris program were good, but this puts us to shame."[70]

In response to new directions in NASA programs and MSFC's role, the Marshall Center's organization experienced several adjustments after 1969. By 1972, the IO segments operated as individual program offices, reporting directly to the head of the Center. The R&DO labs were set up as the Directorate of Science and Engineering, along with several other Directorate organizations. Under the new scheme, the Saturn Program Office contained all of the various stage and engine offices for the Saturn IB and Saturn V, along with the PCC. Many of the individuals associated with the original Saturn V Program Office took new positions involving Skylab, the Space Shuttle, and other projects, shaping their experience and skills towards the achievement of new goals in management (Fig. 24).

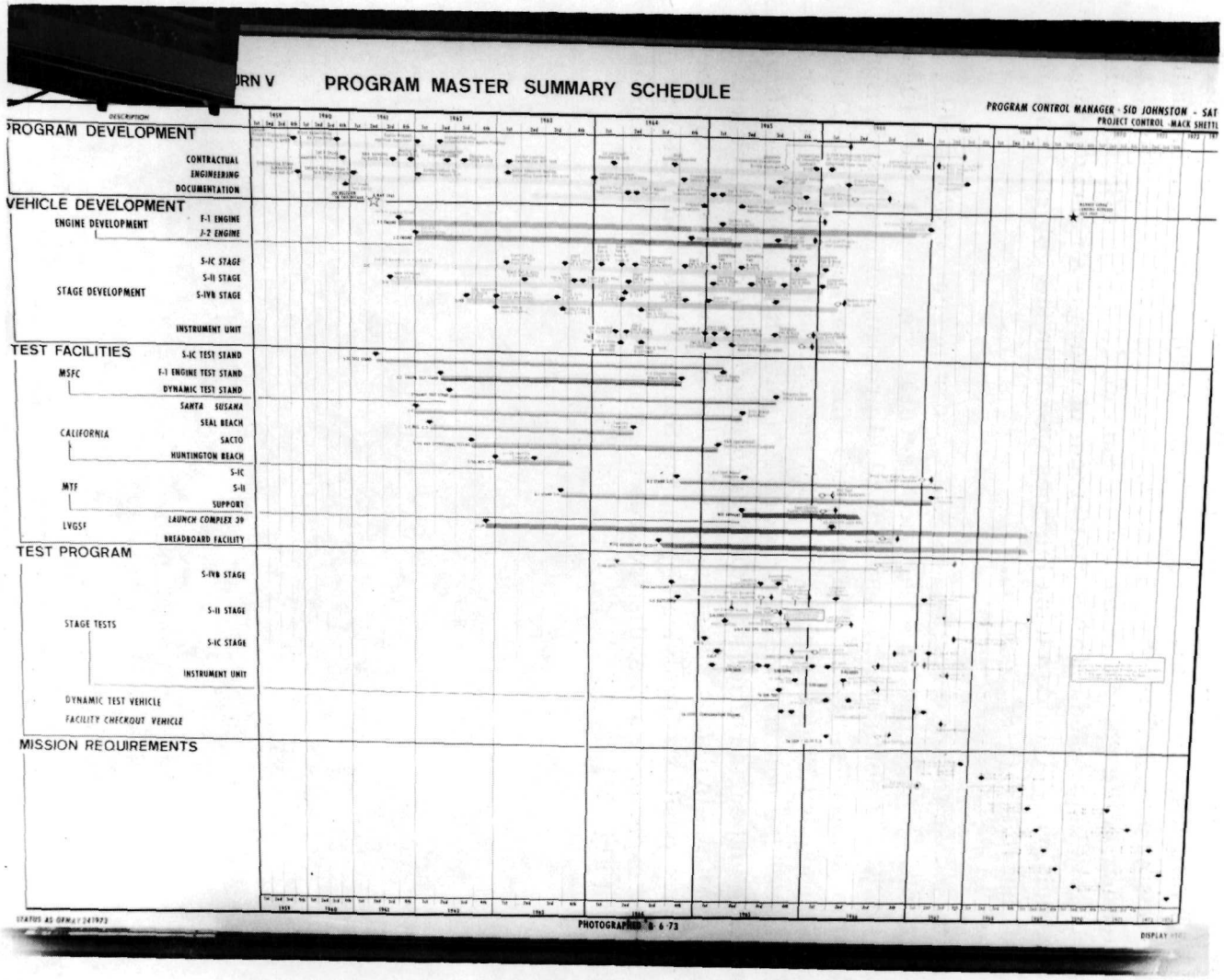


Figure 24. Saturn master schedule summary.

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The author worked as a contract historian for the Saturn History Project, 1970-72, and several of the interviews noted were either conducted or acquired during that period. Interview tapes and transcripts are in the Saturn History Project files.

1. Wernher von Braun, "Management in Rocket Research." A speech to the Sixteenth National Conference on the Management of Research, held at French Lick, Indiana (September 18, 1972). Reprinted in Business Horizons (Winter, 1962).

2. For a general historical overview of this era, see, Wernher von Braun and Frederick I. Ordway III, A History of Rocketry and Space Travel (New York, 1969). The Peenemuende days are covered in Walter Dornberger, V-2 (New York, 1954). The story of Operation Paperclip, Fort Bliss, ABMA, and the NASA transfer is summarized by David S. Akens, Historical Origins of the George C. Marshall Space Flight Center, MSFC Historical Monograph No. 1 (December, 1960). See also, von Braun, "Management."

3. Akens, Historical Origins 71-73; von Braun, "Management."

4. Eberhard Rees, "Project and Systems Management." A speech to the XVI World Management Congress, held at Munich, Germany (October 25, 1972). For the early years of NASA's managerial development, see, Robert L. Rosholt, An Administrative History of NASA, 1958-1963, National Aeronautics and Space Administration, NASA SP-4101 (1966). Wernher von Braun left in 1970 to take a position at NASA Headquarters. Eberhard Rees had been one of the early members of the von Braun team in Germany and for many years, both at ABMA and MSFC, had served as deputy director for technical operations in von Braun's office. Rees headed MSFC from 1970 to 1973 and was succeeded by Rocco Petrone.

5. Over a period of years, the names of the contractors, as well as some of the NASA Centers and internal offices, underwent changes. Douglas Aircraft merged with McDonnell Aircraft to become the McDonnell Douglas Aircraft Corporation (MDC). North American Rockwell (NAR) is now Rockwell International. The Manned Spacecraft Center at Houston (MSC) is now the Johnson Space Center.

6. Interviews with William H. Sneed (July 28, 1973); James W. Wiggins (July 31, 1973); Normal L. Cropp, "Evolution of Marshall Space Flight Center Program Management Organization," 8-9. The latter is an unpublished document, prepared in 1972, as part of a management study series for the Program Management Directorate. The author was a veteran MSFC executive.

7. Cropp, "Evolution," 3-4; von Braun, "Management."

8. von Braun, "Management."

9. von Braun, "Management."

10. Rosholt, An Administrative History of NASA, includes a detailed analysis of the reorganization, including organizational charts for both Headquarters and Center levels.

11. Interview with Herman Weidner (August 24, 1971); interview with Wernher von Braun (November 17, 1971). The new director of R&DO, Herman Weidner, was a long-time member of the von Braun team from the Peenemuende era--a man with whom the other von Braun team veterans could work. The new IO director, on the other hand, came from industry, reflecting IO's function in contracting and management. The first IO director was Robert Young, formerly of Aerojet General. He played an interim role for about a year, and was succeeded by General Edwin O'Connor, on leave from the Air Force.

12. The 1963 MSFC reorganization, in effect, reduced the premier position of the technical divisions, or laboratories, and marked a historic break in the evolution of the Peenemuende group. As Bill Sneed recalled the change, it was a very "painful" move for von Braun to make (Sneed interview). In his three page memorandum explaining the change, and

the reasons for it, von Braun's emotions were unusually evident. "In the past, such a paper was needless," he wrote, and went on to explain the requisite logic for the new management responsibility in the program and project offices. "By keeping these principles in mind, and maintaining the spirit of teamwork which has been our tradition, we can adjust to our new conditions and retain our past performance standards." Memo, von Braun to Division Directors and Office Chiefs, "MSFC Management Policy #1 (August 16, 1962). Copy in the files of the Saturn History Project (cited hereafter as SHP Files).

13. Interview with Arthur Rudolph (November 26, 1968).

14. Apollo Program Office, NASA Headquarters, NASA - Apollo Program Management, vol. I (December, 1967), 3.6-3.12. Up to 1967, no single document, or series of documents, had been issued to lay out the overall management picture in detail. In response to many requests for such information, the Apollo Program Office authorized a special descriptive series, summarizing the various elements of management that had developed over the years and that were currently in effect. The project ran to 14 separate volumes, covering each of the Centers involved in the Apollo/Saturn program, as well as each of the major contractors. Huntsville operations were covered in vol. III, Apollo Program Management:MSFC.

15. Cropp, "Evolution," 36-37; interview with George E. Mueller (June 27, 1967).

16. Rudolph interview.

17. Interview with Mack Shettles (July 27, 1973); Rudolph interview.

18. Saturn V Program Control Office, "Saturn V Program Element Plan for Program Management" (August, 1966).

19. Memorandum from Arthur Rudolph, "Saturn V Program Directive #9: Saturn V Program Control System" (April 1, 1965), passim.

20. Saturn V Program Control Office, PEP, "Management," 10, 26, 28. There were eight Inter-Center Panels: Flight Evaluation; Instrumentation & Communications; Flight Mechanics; Electrical; Crew Safety; Launch Operations; Flight Operations.

21. Letter, D. Brainerd Holmes, Director of Manned Space Flight, to R. R. Gilruth, W. von Braun, K. Debus (July 10, 1963); Memorandum, D. Brainerd Holmes, "Panel Review Board" (July 10, 1963) copies in SHP Files; Apollo Program Office, NASA ... Management, vol. I, 3.13-3.14; Curt Hughes, "Saturn Management Concept" (November 20, 1970). This last document is a transcript of a typical presentation made to delegations visiting the Saturn V Program Office to study its operation.

22. Memorandum, R. G. Smith to J. A. Bethay (June 12, 1973); Saturn V Program Control Office, "Saturn V Configuration Management, Program Element Plan" (October 1, 1967) passim; Norman Cropp, "Saturn," 8. The latter is a companion manuscript to Cropp, "Evolution."

23. Rees, "Project Management," 7; memorandum, Donald R. Bowden, "Saturn V Program Interface Management" (1967), copy in SHP Files; Sneed interview.

24. Rees, "Project Management," 8.

25. Memorandum from Oswald Lange, "Working Groups within the Saturn Management Plan" (September 8, 1960), SHP Files; Hughes, "Saturn ... Concept"; Saturn V Program Control Office, PEP, "Management," 12; Saturn V Program Office, "Saturn Management Concept," 27; Shettles interview.

26. von Braun interview; Saturn V Program Control Office, PEP, "Management," 13-15; Cropp, "Saturn," 8; Hughes, "Saturn ... Concept"; Rees, "Project Management," 14. Rudolph did not like frequent staff meetings. Instead, he liked to have fewer meetings in which the programs were discussed and analyzed in depth, leaving the management burden, in the interim, primarily on the shoulders of his Project Offices (Rudolph interview). This meant that the monthly sessions were very long indeed, and one of the standard jokes in Rudolph's office involved

bleary eyed Project Managers, in the early morning hours, dropping notes out of office windows: "Help me--I'm in a Rudolph meeting!" Rudolph enjoyed frequently telling the story himself.

27. Proceedings of the annual program reviews were published by NASA Headquarters, Office of Programs & Special Reports. For example: Program Review: Apollo (November 16, 1966). The text consists of transcriptions of the complete remarks made by the participants, accompanied by the charts and slides used in their presentations. For the Apollo Executive Group, see, Interview with George E. Mueller; Apollo Program Office, NASA ... Management, vol. I, 3.6.

28. Saturn V Program Control Office, PEP, "Management," 10; Hughes, "Saturn ... Concept"; Shettles interview. For technical managerial reasons, the RMO staffs at Kennedy Space Center and at North American reported directly to Rudolph's office.

29. Rees, "Project Management," 10, 16-17.

30. Transcription of remarks by General Phillips, in NASA Headquarters, Office of Programs and Special Reports, Program Review: Apollo (November 23, 1964), 159.

31. Transcription of remarks by Lee James, Program Review (November 23, 1964), 56-57.

32. Remarks by Lee James, ibid., 55-57. The Battleship test was an early phase in which thick, heavy-duty propellant tanks were used, hence the name. The All Systems Test, as the name implied, involved thorough testing of all related systems: electrical, mechanical, pneumatic, and so on.

33. Ibid.

34. David S. Akens, Saturn Illustrated Chronology, MSFC, MHR-5 (January 20, 1971), 120-121.

35. Transcription of remarks by General Edwin O'Connor, Program Review (November 16, 1965), 81-83.

36. Akens, Saturn Illustrated Chronology, 142-43.

37. Transcription of remarks by General Samuel Phillips, Program Review (November 15, 1966), 37-42.

38. Rudolph interview; Sneed interview; interview with Sidney Johnston (July 26, 1973).

39. Comments from a privileged source, a person in the upper management levels.

40. Rees, "Project Management," 17.

41. Hughes, "Saturn ... Concept"; Rees, "Project Management," 11; Sneed interview, Rudolph interview. Cost plus award fee contracts are a type of incentivization which involves contractor performance monitored by project personnel and a board. The contractor is judged on various effectiveness factors whose criteria are subject to periodic revisions during the contract, whereas the criteria for the CPIF contract are totally definitized as part of the basic contract.

42. MSFC, Saturn V Reliability and Quality Program Plan, MM 5300.2A (August, 1968); Rees, "Project Management," 8-9.

43. Ray Kline, "Memo for Record: Notes on Management Advisory Committe Meeting at Michoud on June 4, 1964" (June 26, 1964). For the Douglas operation, see L. C. Wilson, et.al., "Development of Separable Connectors for the Saturn S-IV Stage," Douglas Paper #3552 (1966), 3-8; R. B. Wilson and H. L. Hug, "A Prime Contractor's Reliability Program for Components/Parts for the Douglas S-IVB Stage Project," Douglas Paper #3794 (1966), 1-4. Copies in SHP Files.

44. Transcription of remarks by Lee James, Program Review (November 23, 1964), 58, 60. Rees, "Project Management," 9-10; Rudolph interview.

45. Hughes, "Saturn ... Concept"; Rees, "Project Management," 11; Sneed interview, Rudolph interview.

46. Interview with Mitchell R. Sharpe, August 6, 1973. It would be easy to dismiss such sloganeering, but it was very pervasive and seems to have been taken very seriously. During a tour of contractor facilities in the Los Angeles area in 1971, the author could not help but notice the prominently displayed stickers and placards in engineers' drafting rooms, shop areas, and offices, and the huge banners, proclaiming PRIDE, VIP, etc., hung across the walls of the cavernous buildings where the Saturn V stages were assembled. In cafeterias, and even in executive conference rooms, the coasters for coffee cups and water glasses carried appropriate slogans for "Manned Flight Awareness."

47. Hughes, "Saturn ... Concepts."

48. James Baar and William Howard, Polaris! (New York, 1960), 41-42, 49-51.

49. The Boeing Company, "Management Control Center System," D5-15710 (November 8, 1967), 1.3-.4. While this document does not analyze and describe the PCC at MSFC, it was intended as a comprehensive guideline for control centers in general. It includes the philosophies involved, sample charts, and even detail drawings of sample hardware. As such, it would be a primary document for use in establishing such an operation.

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51. Saturn V Program, "Saturn V PCC."

52. Rees, "Project Management," 15-16; Arthur Rudolph, "Saturn V Management Instruction #14: Saturn V Program Control Center" (April 15, 1966), 1-2.

53. Rudolph, "Saturn V Management Instruction #14," 3-5, 8-9, 14; Rudolph interview, Shettles interview.

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65. Memorandum from Wernher von Braun to O'Connor (IO) and Weidner (R& DO), "R& D Operations and Industrial Operations: Charters and Guidelines for Cooperation" (February 19, 1965). See also, Saturn V Program Control Office, "Saturn V Program Element Plan for Financial and Manpower Management," (October, 1967).

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68. Saturn V Program Control Office, PEP, "Management," 9.

69. Sneed interview; Marshall Star (November 3, 1965). Direct quote supplied by Bill Sneed, from notes taken at the time.

70. Shettles interview; Sneed interview. Copies of various presentations are housed in the files of the Saturn V Program Control Office. Direct quote supplied by Bill Sneed, from notes taken at the time.

BIOGRAPHICAL NOTE ABOUT THE AUTHOR

While a student at Doane College, Roger Bilstein participated in the Washington Semester Program in political science, sponsored by American University in Washington, D. C. He received his B.A. degree from Doane College (1959) and completed his graduate studies at the Ohio State University (M.A. 1960; PhD 1965), where he specialized in recent U.S. history, especially technology and aerospace history. As a graduate student, he was named Mershon Fellow in National Security Policy Studies (1960-61) and was a Teaching Assistant (1961-1965). From 1965 to 1972, he was on the faculty of the University of Wisconsin — Whitewater, and participated in the American Studies Program there. He was the recipient of several Wisconsin Regents Study and Travel Grants. During 1970-1972, Dr. Bilstein was on leave of absence from UW — W and acted as Senior Research Associate for the Saturn History Project at the Research Institute, University of Alabama in Huntsville. Funded by the National Aeronautics and Space Administration, the coauthored effort involved the preparation of the official NASA history of the Apollo/Saturn launch vehicles. In 1972, Dr. Bilstein joined the faculty of the University of Illinois with a joint appointment involving the Institute of Aviation and the Department of History. In the summer of 1973, he was named as a Summer Faculty Fellow in a program sponsored by NASA and the American Society for Engineering Education and worked at NASA's Marshall Space Flight Center. Dr. Bilstein is a licensed private pilot, and his book reviews and articles on various aspects of the history of technology and aerospace history have appeared in U.S. and international scholarly journals. He is the Editor-in-Chief of a textbook, Fundamentals of Aviation and Space Technology (1974), published by the Institute of Aviation of the University of Illinois. In 1974, he joined the faculty of the University of Houston/Clear Lake City, a new upper-level university with enrollment limited to juniors, seniors, and graduate students.

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