Chapter II

The Center in the Saturn Years: Culture, Choice, and Change

When Huntsville's rocketeers transferred from the Army, they brought a unique organizational culture to NASA. Marshall's laboratories had a technical ethos which sought control over all phases of a space project, from design, development, manufacture, and testing, all the way to launch. The labs could, and did, manufacture anything from subscale engineering prototypes to Redstone missiles. The Center's contract managers already had experience in directing missile development. Heading the team was von Braun, one of the most charismatic leaders of any American organization.

In its first decade in NASA, the Marshall Center helped make American space plans, and those plans in turn reshaped the Center. The Center influenced decisions to undertake a manned lunar landing, select the Saturn launch vehicles, and choose a mode for going to the Moon, and in the process formed patterns of interaction with NASA Headquarters and other field centers. The plans and the subsequent work on the Saturn boosters changed Marshall in various ways, leading it to add personnel and facilities, enhance its capabilities in project management and systems engineering, and help NASA create a launch center. Indeed, it would be no exaggeration to say that the Apollo Program shaped Marshall's first decade.

Dirty Hands

In 1960 NASA's newest field center was fundamentally a rocketry research organization with a professional engineering code that sought hands-on control over all phases of booster development and operation. The foundation of Marshall's organization and culture in 1960 was the "Army arsenal system" in which Civil Servants performed all types of technical work. Rather than being primarily supervisors of contractors, Center personnel were hands-on designers, testers, manufacturers, and operators.

The arsenal approach was a legacy from the German and American military but was similar to the laboratory culture of NASA's other field centers. Government research organizations, whether military or civilian, evolved because business initially had limited interest and expertise in rocketry or aerospace research. Moreover, in the 1950s, rocketry was still relatively unexplored technology, and pioneers in the field faced many unanticipated problems that made contracting problematic. As Dr. Ernst Stuhlinger, the chief of the Center's Research Projects laboratory, recalled, "it is very difficult to tell them [industry] just exactly what to build, because we don't know ourselves before we have begun with some experiments."[1] Dr. William Lucas, a materials specialist in the Structures and Mechanics Lab and later Marshall's Center director, remembered that "in the early days, we could go from the idea to the proving ground," because there were "not [industry] people who wanted to do this or were able to do it."

The ABMA experience with the Redstone missile illustrated the problem. When ABMA asked industry to make bids for the project, no business responded, and the Department of Defense had to convince Chrysler Corporation to take on the job. Even so ABMA was the innovator; its labs designed and built the first 17 Redstones, trained Chrysler personnel, and only then turned the work over to the company. Lucas explained "it wasn't a matter of going to the contractor and saying 'do this for us,'" and then assigning the firm a task it had done before. Marshall had to find contractors and say "here's what we want you to do" and then show them how to do it.[2]

The arsenal system showed in various ways. Despite Marshall's location among wooded hills and lush valleys, the physical appearance of the Center was industrial and was in stark contrast to some other NASA field centers that looked like college campuses. The center's layout displayed a functional character, with areas for management, engineering, manufacturing, and testing. The architecture also looked industrial, with utilitarian office buildings, cavernous factory structures, and huge test facilities, all linked by a web of electrical wires and above-ground pipes.

Marshall's original organization was also industrial and much like a large aerospace company. Each of the Center's eight laboratories had a functional specialty and its own technical facilities; together they could design, test, and build rockets or almost any other kind of aerospace hardware. The Aeroballistics Laboratory, later called Aero-Astrodynamics, used wind tunnels and vacuum

Drafting specialists from the Propulsion and Vehicle Engineering Lab work in the Huntsville Industrial Center building.

chambers to study air flows on vehicles and developed programs to control them. The Guidance and Control Laboratory, later named Astrionics, developed systems and components for communications, guidance and control, and electrical power. Its facilities and equipment ranged from standard bench equipment like oscilloscopes to specialized test equipment, telemetry instruments, and simulators. The Research Projects Laboratory, later called Space Sciences, used smaller "plug-in" equipment for scientific research in physics, astrophysics, and thermodynamics; the lab also provided scientific support for engineering projects, helping develop several spacecraft in the Explorer series of satellites. The Computation Laboratory's computers helped administer the Center and supported research activities in the other labs.

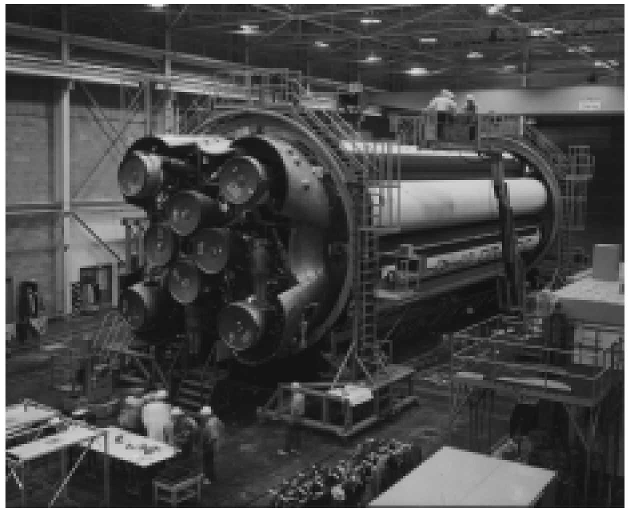
The SA–2 booster is in final assembly stages at the NASA Marshall Space Flight Center, Huntsville, AL.

The Structures and Mechanics Lab, later called Propulsion and Vehicle Engineering, had broad capabilities in rocketry, with specialties in structural and mechanical design, materials analysis, and systems engineering. It could conduct heat transfer research, chemical and radiation analyses, cryogenic tests, and fluid and hydraulic studies. With its capability to make prototypes and test components, the Structures and Mechanics lab in itself had capabilities comparable to a rocketry corporation. The Manufacturing Engineering Laboratory could manufacture large prototypes and had high bay structures with cranes, large access doors, and machine shops. The Test Laboratory operated the huge test stands that handled the smoke-and-fire rocket tests. The Quality Laboratory also tested vehicle systems and subsystems, and had facilities ranging from high bay buildings to small bench equipment for electronic calibration tests on flight components. The Launch Operations lab had facilities in Huntsville and at Merritt Island, Florida. All in all, Marshall's laboratories had nearly comprehensive capabilities in propulsion and aerospace engineering; the Center was almost a space agency in miniature.[3]

Center officials believed in the arsenal system. Convinced that it should be more than a transitionary step in the maturation of aerospace industry, they argued that the system improved quality, accelerated progress, and contained costs. Von Braun argued that in-house design and manufacturing capability attracted engineers and specialists who wanted to build things rather than shuffle paper. It also trained young engineers fresh out of college, who had more theoretical than practical knowledge, and gave them industrial experience.[4]

Marshall engineers also believed that the arsenal system improved quality and reduced red tape. They appreciated working with in-house machinists and craftsmen. Typical of their views were the comments of Peter Broussard, an engineer in the Sensor Branch of the Guidance and Control Lab whose team developed the navigation system for the lunar roving vehicle. In an arsenal system, Broussard said, "you can work hand in glove with the man that is doing it. He could call you and say, 'I don't understand this; come over and talk to me.'" Later contracting methods, he believed, were "far more expensive and far less efficient" and even after a slow process "you may not get what you contracted for."[5]

In addition, the arsenal system and the technical depth of the labs helped the Center direct its contractors. Marshall officials often contrasted the arsenal system to the Air Force system which gave business contractors much wider scope.


Saturn I booster checkout in 1961.

Lee B. James, Saturn I and Saturn V project manager, said that "the difference in managing a program at Marshall has always been the laboratories, which give our Center unusual depth." Marshall's engineers had detailed knowledge which allowed for meticulous design requirements in their contracts. In some cases, like the Redstone and the first stages for the Saturn I and V, Center personnel invented manufacturing methods and built full-scale prototypes to accelerate progress. Moreover, knowledge of engineering and manufacturing detail allowed Marshall to evaluate contractors. Building prototypes was especially effective because Marshall learned about costs, creating a "yardstick" to measure contractor prices. Karl Heimburg, chief of the Test Lab, recalled that "what industry didn't like was, since we made it ourselves here, we knew what it would cost. They would come out with a flat sum that was three times as high as it should cost. We said 'if you do it this way, we will manufacture it ourselves.' So you see they didn't like it at all that we dictated it." [6]

The intimacy with hardware produced by arsenal practice and laboratory culture affected nearly everything at the Center. Marshall developed customs of conservative engineering, meticulous quality control, testing-to-failure, dirty-hands management, matrix organization, automatic responsibility, and open communications.

Conservative engineering was a natural lesson from rocketry experience. Rockets put extreme stresses on technology, and propulsion pioneers often faced fiery failures. Lucas recalled watching his first Redstone launch. "It got about thirty feet off the ground and fell back and exploded." During any launch or test, he noted, "there were thousands of things that could go wrong," and "we knew at any time that one lousy little twenty-five cent part somewhere could cost you the whole ball game." [7]

Center engineers developed a habit of conservatism in engineering, preferring things simple and sturdy, tried and true. James Odom, chief engineer for the Saturn S–II stage, recalled that Marshall designed its hardware to be "stout," often to the point of being "over-stout." Conservative design led to technology with high margins of safety and reliability.[8] Conservatism showed in an "incremental" approach to innovation; rather than designing from scratch, Marshall preferred to build on proven concepts. For instance, the Saturn rocket engines and stages, while innovative in size, materials, and manufacturing processes, drew on the engineering knowledge and research programs of military rocketry. Even more telling, the Center used successful technology in new ways, most famously helping conceive the conversion of a Saturn S–IVB rocket stage into the *Skylab* space station. Flight tests of rockets were also conservative; under the Center's original stage-by-stage approach, first stages flew first without upper stages, and only after successful flights were live upper stages added.

Marshall used rigorous quality control and test practices. Again rocketry experience had taught Center personnel that quality had to be built into hardware from the beginning. As von Braun observed, it was "better to build a rocket in the factory than on the launch pad." The Center, especially its Quality and Reliability Assurance Lab, taught contractors how to ensure quality products and monitored their manufacturing and test procedures. Part of this was what Dieter Grau, the lab's chief, called a "rigid inspection program" in which all Center personnel, rather than only designated quality inspectors, were responsible for quality.[9]

When Center people applied this approach to contractors, they called the practice "penetration." Marshall believed in giving contractors specific design requirements and then observing their operations closely to ensure that the requirements were met. The Center's resident manager offices were key tools of penetration. Located at major contractors' plants, each had a staff of administrators and engineers who monitored work and acted as liaison between the contractor and Marshall's labs. Center specialists carefully watched the manufacturing process, discussed problems with contractor personnel, and as a result often knew more about the corporation and its products than the corporation's own management. During the resource-rich Saturn years, Marshall assigned as much as one-tenth of its workforce to resident offices. One Center manager admitted that penetration was often "traumatic" for the company at first, especially for those accustomed to working under Air Force supervision. Compared to Marshall, one contractor pointed out, the Air Force was "not in your pants all the time." [10]

One Marshall project official noted that during the Saturn program the Center would "penetrate down to excruciating detail on a continuous basis. Engineer to engineer. Designer to designer." Headquarters sometimes questioned such practices and wanted Marshall to trust its contractors more. During a visit by NASA Administrator James Webb, Center engineers showed him a rag they had found in a rocket engine and explained that such problems revealed why they mistrusted contractors.[11]

Center personnel contrasted their method of monitoring contracts with the methods used by the Air Force. When Marshall replaced the Air Force as monitor of the Centaur rocket contract, the difference became clear. The Air Force had assigned 8 officials to the project, while Marshall assigned 140. One Center engineer noted that aerospace contractors wanted Marshall to manage like the Air Force: "they [the government] give you [the contractor] the money; you go away; you deliver a product; they buy it." Marshall, he noted, did not work like this because the Center did not want to get "taken to the cleaners."[12]

Marshall people also contrasted their quality practices with those of private industry. For most of its hardware, aerospace industry and the military relied on mass production. In mass production, cheapness compensated for defects, and when a customer complained about product quality, he would receive a replacement. But NASA's launch vehicles were not mass produced, and a failure in the propulsion system could be catastrophic rather than merely inconvenient. As Grau explained, "you cannot put a man on a [launch vehicle] and say 'if it fails, and if you get killed, take the next one.'" Consequently Marshall had to change the mentality of its contractors from "mass production with acceptable errors" to "craftsmanship—do it right the first time—with no error."[13]

Marshall also questioned the statistical risk assessment methods used by aerospace contractors and the military. With mass production, engineers could use random tests and statistical measures to isolate defects and predict reliability. But since NASA built only a few vehicles and required that each work flawlessly, random tests and statistical measures of reliability seemed questionable to Marshall engineers. In 1961, Eberhard Rees, Marshall's deputy technical director, observed that NASA rules required reliability statistics, but that he did not trust the numbers; his attitude was "if they [Headquarters managers] are happy with the figures let them have it." According to Marshall lore, Headquarters asked von Braun for a reliability figure on a Saturn stage and he replied by saying it was 0.99999 reliable. The figure, the Center director said, came from calling his lab directors and asking them if the stage would cause trouble. Von Braun called five directors and they replied in turn "Nein," "Nein," "Nein," "Nein," "Nein."[14]

Marshall's confidence in its hardware resulted from rigorous testing. All the labs performed tests, and two labs, the Test Lab and the Quality Assurance and Reliability Laboratory, independently checked the work of the other labs and contractors. The two labs, remembered Walter Haeussermann, chief of the Astrionics Lab, sought to prevent the "camouflaging of short-comings." Heimburg believed that experience in rocketry had convinced Center leaders that safety and economy depended on thorough tests on the ground; with severe tests, engineers could detect and correct problems and thus minimize costly, or even deadly, launch mishaps and failures. In a response to questions from a NASA propulsion committee in 1961, Heimburg explained the Marshall policy that "each sensitive event, component, subassembly, and stage should be subjected to design evaluation testing." The tests should be realistic, using full-scale flight equipment rather than subscale models, and should occur at "exaggerated environmental conditions." The practice allowed Marshall engineers to discover failures and flaws. The goal, Lucas recalled, was to "test until we wear it out" in order to understand weaknesses. Marshall insisted that its contractors bring their hardware to Huntsville for tests, even after that hardware had already been tested at contractor facilities.

Thorough tests were of course expensive. Tests accounted for one-half of the Saturn project's total cost as measured in man-hours and material resources. Heimburg justified these costs in 1961, arguing that "a shortage of funds means a minimum of ground testing, below the optimum, which means increased mission failures. The money temporarily saved, and more, will be spent later in repetition of testing." Lucas noted that NASA reduced testing in the 1970s and based its decision on "so-called economics." Reducing tests to save money, he believed, was "one of the costliest mistakes" that NASA ever made; "maybe we overdid it [testing] on the Saturn program, but we clearly underdid it on everything since then."[15]

Organizational and managerial patterns also evolved from Marshall's arsenal practices and research culture. The key organizational custom was "automatic responsibility." Konrad Dannenberg, a Center veteran, explained that the labs, regardless of whether they had formal authority, were automatically responsible for problems in their specialty. They could not, he said, "sit in the corner" and "wait until something went wrong and say 'I told you so.'" James believed that the practice helped expedite problem solving because the lab experts "feel responsible [and] they bring these things to the program manager's attention without being asked."[16]

Automatic responsibility helped produce a matrix organization based on interdisciplinary groups. The practice, which von Braun called "teamwork," evolved from the complex tasks of aerospace and rocketry engineering. Because problems overlapped engineering specialties, no single discipline could design, develop, and evaluate an entire launch vehicle or even major subsystems. Success depended on the cooperation of specialists from many labs.[17] Moreover, as Dr. Mathias P. Siebel, deputy director of Marshall's Manufacturing Engineering Laboratory, observed, the Center was making "small quantities of high cost articles" that had to work "the first time." This meant, Siebel added, that each vehicle was a research project based on continuous innovation in response to unpredictable technical problems and program changes. Solving the problems systematically required teams with experts in design, manufacturing, quality control, testing, and operations.[18]

Accordingly, Marshall had many task-specific, interdisciplinary teams. At the beginning of each project, lab chiefs and project managers formed temporary teams with members drawn from several labs. The project managers had responsibility for budgets and schedule, and the lab chiefs had authority over technical problems. Each team and its contractor counterpart worked on a specific problem until it was resolved. For example, specialists from several labs and contractors cooperated closely on the guidance and control systems for the Saturn V. The Astrionics Lab designed the guidance and control processors and built prototypes, IBM manufactured the flight models, the Quality Lab tested the processors, the Aeroballistics Lab developed guidance equations for the processors, and the Computation Lab simulated flights in its computers and generated data for the guidance equations.

Leland Belew remembered that teamwork meant that "you would see every major decision treated by the total organization. It was a fishbowl type operation. It was 20/20 visibility from the outside in." The systematic approach to engineering that Marshall used in the 1960s, Belew believed, anticipated 1980s innovations associated with management guru W. Edwards Deming or systems like Total Quality Management.[19]

Another central feature of the laboratory culture was that Center managers were intimately involved in technical matters. In-house research and development, von Braun said, helped top officials "keep their knowledge up to date and judgment sharp by keeping their hands dirty at the work bench." He believed that managers with "dirty hands" were both planners and doers, and consequently were more effective leaders.[20]

Von Braun watches a Saturn launch.

Von Braun was the model of the dirty-hands manager and his persona and management style have generated much comment. One commentator described von Braun as the "managerial lord" of Marshall's "feudal order." He ruled over German "vassals," each of whom had rights in their fiefs and responsibilities to their lord. The Marshall leader, the novelist and pundit Norman Mailer wrote, was "the deus ex machina of the big boosters" who corporate managers worshipped as the "high priest" of innovative organizations.[21]

Marshall colleagues recalled von Braun's charisma. Dannenberg noted that von Braun inspired each employee to feel like he was "the second most important man" in the world working for the most important man. Ruth von Saurma, who as a member of the public affairs staff often helped out with international correspondence, recalled that "there was hardly anyone who did not like him and look up to him, although he never looked down on anyone. He always seemed to be on the same level as the person he would be talking to. What was fantastic was that individuals grew tremendously under his leadership and performed so much more for him as a group than they ever would have been able to do individually."[22] "Wernher von Braun was not a dictator—he didn't have to be," Georg von Tiesenhausen insisted. "His personality was such, his authority was such, that everyone did what he wanted anyway." Von Braun had confidence in his ability to pick the right person for a job, and delegated responsibility.[23] His dynamism challenged people. "Von Braun was always overflowing with ideas," according to Dannenberg.[24]

Von Braun, Stuhlinger remembered, "never said any disparaging word or derogatory word about anyone." This habit encouraged the openness and cooperation necessary for problem-solving. Center veterans recollected how von Braun had responded to a young engineer who admitted an error. The man had violated a launch rule by making a last-minute adjustment to a control device on a Redstone, and thereby had caused the vehicle to fly out of control. Afterwards the engineer admitted his mistake, and von Braun, happy to learn the source of the failure and wanting to reward honesty, brought the man a bottle of champagne.[25]

Wernher von Braun suited up for conducting tests in Marshall's Neutral Buoyancy Simulator.

Marshall's first leader was also the Agency's master publicist and lobbyist. In addition to appearances before congressional committees, von Braun averaged nearly 150 articles and speeches a year, and kept two full-time writers busy in Marshall's Public Affairs Office. Between 1963 and 1973 he contributed monthly articles to the magazine *Popular Science*. His topics were diverse and included anticommunism, Christianity, and Creationism, but the vast majority promoted space exploration and research. Recognizing that space projects needed public support, his motto was "Early to bed, early to rise, work like hell and advertise!" Such boostership made von Braun, in the words of Amos Crisp, one of his writers, "Mister Space" in the 1960s.[26] Norman Mailer observed that von Braun was the only NASA manager known to the public and was "the real engineer, the spiritual leader, the inventor, the force, the philosopher, the genius! of America's Space Program."[27]

In his space speeches and articles, Marshall's director made NASA projects, plans, and technology understandable to the public. More importantly he sold the excitement, significance, and benefits of space exploration. Von Braun pointed out technological spinoffs and scientific discoveries, but mainly argued that the greatest benefit of the space program was in generating new challenges. Spurred by space exploration, scientists, engineers, and technicians innovated faster and teachers educated students better. In the long-term, he thought, meeting the challenges of space boosted economic growth.[28]

Rees, von Braun's deputy since Peenemünde, complemented his chief's leadership style. Von Braun was the visionary, Rees the practical manager; von Braun inspired people to conceive new ideas, Rees drove them to complete old tasks. His direct supervision became more important as von Braun's public appearances absorbed more of the Center director's time. Rees "paid attention to minor details. He was the technical man, but von Braun always floated with his feet above the ground," von Tiesenhausen explained. "Dr. Rees would say to Wernher, 'Now simmer down.'"[29]

Von Braun expounded a philosophy of management, and some of its elements became parts of Marshall's culture. Teamwork in a research and development organization, he argued, depended on a proper balance between centralized management and decentralized specialists. Without centralization, the team could not set common goals and harmonize differences. But managers in an ivory tower could not command cooperation or solve technical problems "in a high-handed fashion." Without decentralization, specialized technicians could not develop knowledge and work together. For von Braun, managing teamwork required "communication" between managers and specialists; and communication depended on "a kind of four-way stretch: up and down the organizational chart, and laterally in both directions."[30]

Two of von Braun's methods of communication, "board meetings" and "weekly notes," became Marshall traditions. The Marshall director had weekly meetings of his "board" of top Center officials, laboratory directors, project managers, and invited specialists. The meetings had formal presentations, but their primary feature was the free, often heated, discussion of problems and policies. Von Braun presided over the discussion without dominating the exchange.

In board meetings and in other Center-level meetings he showed his skill as a systems engineer and manager. Subordinates marveled at von Braun's vision of space exploration, understanding of arcane technical and scientific issues, and ability to recall details and fit them into patterns. They wondered at his ability to summarize complex and confused presentations in a few sentences, translate technical jargon, and integrate conflicting opinion. One colleague recalled how experts "would be talking almost like in unknown tongues" and "finally von Braun would take over and explain what was being said in terms that everybody could understand." Another remembered that "von Braun's gift was, after listening to each one, to join all the information into one package that each one agreed to." The consensus and clear policy that emerged at the top helped give Marshall a very disciplined organization.[31]

While meetings were common in research organizations, von Braun's "weekly notes" were unique to Marshall. Under his direction, the Center's laboratory chiefs and project managers submitted a single page weekly summary of their activities and problems. Von Braun scribbled comments and recommendations in the margins and circulated copies to all top officials. Marshall people eagerly read the notes and used them as a forum for discussing technical problems, arguing policy issues, complaining about inadequate resources and cooperation, and discussing solutions. The benefits multiplied because many superiors generated information for their "Monday Notes" by having subordinates submit "Friday Notes." In the process of learning about the problems and ideas of other officials, Marshall's managers could develop a holistic view of the Center and determine how to synthesize their part with the whole. Later Center directors continued von Braun's weekly notes, imitating his use of communication networks as tools for managing teamwork.[32]

The Marshall team's arsenal practices and laboratory culture were sources of strength during the 1960s and early 1970s. Although much of the original culture persisted, the Center's participation in the Apollo Program would impose political and managerial pressures that led in new directions.

Planning and Propulsion

When members of the Development Operations Division of ABMA became NASA employees in 1960, America's civilian space policy was still in flux. Over the next few years, American leaders and NASA officials made important decisions, eventually choosing the Apollo lunar landing mission and giving Marshall its task of producing the Saturn launch vehicles. These discussions and decisions mixed scientific and technical issues with strategic and political ones. Lucas recalled that "some of the most significant decisions made in the Saturn program had little to do with engineering. They were mostly political. To be successful in a major project like that, you have to have a national commitment to it, you have to have a defined goal, you have to have a timetable, and you have to have resources."[33]

In the late 1950s American space plans developed in the political context of the Cold War and competition with the Soviet Union. Many Americans feared the military threat of apparent Soviet supremacy in rocketry after the success of the Sputnik satellite in October 1957. The Eisenhower administration had photos from U–2 spy planes to show that no "missile gap" existed, but refused to release this information and compromise its source. Consequently fears persisted, and politicians, public officials, journalists, and scientists debated alternative ways to promote American progress in space.

While still in the Army, the rocket group in Huntsville participated in the national discussions about future space missions and launch vehicles. In early 1958 von Braun stood in the spotlight of Explorer I's success and appeared before Congress to lobby for more space exploration and for a trip to the Moon. In June 1959, General Medaris had ABMA release a "Project Horizon" plan which proposed to establish a permanent, 12-person lunar outpost by 1966.[34]

ABMA also contributed to planning of new launch vehicles. In 1957 the team proposed construction of a clustered-engine booster with 1.5 million pounds of thrust. By August the following year the ARPA of the Department of Defense had agreed to provide research and development funding for the new vehicle, called the Juno V and later the Saturn I, and in December ABMA began working on the vehicle as a subcontractor to NASA. Concurrently ABMA worked with military and NASA planners in choosing advanced vehicle designs and upper-stage configurations appropriate to missions in Earth orbit or lunar voyages. ABMA's engineers examined concepts using space planes, solid-fuel rockets, or various liquid fuels. By 1960, NASA's propulsion planning committee, chaired by Abe Silverstein, formerly of Lewis Research Center, had selected liquid hydrogen, a relatively new but powerful fuel, for the upper stage. By late in the year, NASA and Marshall had begun preliminary design of an even more powerful Saturn. Later called the Saturn V, its first stage would use a cluster of F–1 engines, originally developed by Rocketdyne for the Air Force, each with 1.5 million pounds of thrust.[35]

In the spring of 1961, the new administration of John F. Kennedy chose a lunar landing as the primary task of space exploration. Although the choice rested on technical data from NASA committees and special space policy groups, it depended more on political considerations. The Kennedy administration wanted to ease the anxieties of the American public and bolster national prestige by achieving a dramatic first in space exploration. Staging such a drama would demonstrate the superiority of the American system of enterprise, management, technology, and science. The Kennedy people defined space as a "new frontier" and believed that exploring it would promote progress. Accordingly in his State of the Union message on 25 May 1961, President Kennedy asked for a national commitment to "landing a man on the Moon, and returning him safely to the Earth" before the decade was out. Congress endorsed his request, and NASA created the Apollo Program to put "man-on-the-Moon."[36]

With a clear mission and timetable, NASA and science planners within the Kennedy administration now began studying methods for getting to the Moon. This "mode" decision was difficult because the method had to be economical in time and money, technically feasible, and acceptable within NASA.

The Agency made this decision based on consultations between NASA Headquarters and its field organizations. The groups responsible for human space flight—Marshall and the STG—were especially influential. The Agency had formed the STG, composed of aeronautical engineers from the Langley Research Center and led by Robert Gilruth, to manage the manned satellite program called Project Mercury. By late in 1961 NASA had redesignated the group as the Manned Spacecraft Center (MSC), given it responsibility for manned spacecraft, astronauts, and mission operations, and selected Houston, Texas, as its permanent site. Over the decades the history of the MSC and Marshall would be intertwined; although partners who worked well together, they were sometimes competitors who struggled for resources and control over projects.[37]

From 1960 to 1962, NASA conducted studies of various lunar mission modes, evaluating each plan according to weight margins, guidance accuracy, communications, reliability, development complexity, schedules, costs, flexibility, growth potential, and military usefulness. Marshall personnel investigated two modes, "direct ascent" and "Earth orbital rendezvous." Direct ascent would limit the number of vehicles and launches. A Nova booster, a sort of super-Saturn, would launch one heavy spacecraft, which would travel to the Moon, land on the surface, lift off, and return to Earth. Earth orbital rendezvous, referred to as EOR, could be traced to von Braun's 1952 articles in *Collier's* and had two versions, each depending on Saturn V boosters rather than a Nova. One "connecting" version of EOR would divide the heavy spacecraft in two parts, launch each separately, and integrate them in Earth orbit. The other "fueling" mode would launch the heavy spacecraft with one Saturn booster and its fuel in another, then transfer the fuel in Earth orbit.[38]

The direct ascent mode fell out of favor by the spring 1962. Although officials at Headquarters, the MSC, and Marshall believed that a powerful Nova booster would be useful for a space station, a lunar base, or interplanetary exploration, planners concluded that Nova was too big a leap beyond existing technology and doubted that it could be ready by the end of the decade. Preliminary designs called for the Nova to be twice as powerful as the Saturn V and to have 10 F–1 engines for its first stage. It would be so big—50 feet in diameter in contrast to the Saturn V's 35 feet—that it would not fit test stands and assembly buildings. Moreover, Marshall expected that Nova would be even more technically difficult to develop than Saturn, and they doubted that they could develop two super-boosters at one time, especially if each siphoned money away from the other.[39]

Marshall's dire forecasts about the Nova led to criticism of the Center's commitment to liquid fuels. The criticism focused on Marshall's plans for a liquid-fueled version and failure to study a potentially less expensive and more powerful solid-fuel rocket. Maxime Faget of the MSC later contended that Marshall engineers were "liquid-fuel people" who did not "trust" solid fuels and "tried to think of everything wrong with solids they could." At the time, Marshall did not seriously consider solid rockets because Center propulsion engineers doubted their safety for human flight. Dannenberg pointed out that solid-rocket engines kept burning once ignited; liquid engines, in contrast, could be shut off should dangers develop.[40]

Although the solid-rocket versus liquid-rocket controversy would reappear in NASA history, the issue was moot in Apollo planning. The Nova, whatever its fuel, depended on missions to justify it and commitments to fund it. Von Braun argued that going ahead with Nova meant "giving up the race to put a man on the Moon in this decade even before we started." By late 1961, in contrast, preliminary research for the Saturn V was well underway. Thus once NASA decided that direct ascent could not meet its goal, the Agency stopped funding Nova, and Marshall's rocket designers quietly swept its plans from their drafting tables.[41]

By early 1962 mode options narrowed to a choice between EOR and LOR, short for lunar orbital rendezvous. The LOR mode called for two light, specialized spacecraft, a command spacecraft and a lunar lander-launcher. The two craft would travel to the Moon together. From lunar orbit, the lunar craft, more light in weight than its EOR counterpart, would descend to the Moon, blast off from the surface, rendezvous in lunar orbit with the command craft, and then be jettisoned. John Houbolt, an engineer from the Langley Research Center, was the great booster of LOR. Initially both Marshall and the MSC challenged his ideas, because his plan called for computer-controlled rocket firings behind the Moon and his estimates for the weight of the lunar craft were very low and optimistic. By January 1962, however, Houbolt had convinced the MSC of the utility of LOR.

At this point, the interpretation of the mode decision becomes controversial, and no definitive historical account exists. Participants and historians have offered conflicting accounts of the events leading up to the decision and of its implications. One reason for the lack of consensus has been the partisanship caused by disputes between the MSC and Marshall. The mode options would push the Agency in directions more favorable to one Center than the other. The MSC people favored LOR because developing two specialized spacecraft would be easier then developing a single multipurpose one, and because they could maintain control over human activities in space. Marshall favored EOR because its demands would help the Center grow from propulsion research into

Earth orbital engineering, and would require two Saturn launches per mission and thus generate more responsibility. In an interview in 1970, von Braun downplayed the rivalry. He contended that Headquarters had directed Marshall to study EOR and Houston to study LOR; Marshall never formally endorsed EOR but simply reported on it.[42]

Another reason for disagreements about the mode decision was the use of different engineering criteria. The MSC and most Headquarters officials evaluated any mode based primarily on whether it would technically simplify achievement of Kennedy's objective to land on the Moon by the end of the decade; by these criteria LOR was simplest.[43] Marshall and the PSAC evaluated modes based on the Apollo deadline, but also on ability to promote science and space exploration in the long term. EOR, they thought, would provide technology and experience in refueling, assembly and repair, and rescue in Earth orbit and better allow for a space station or lunar base.[44] The different criteria had created an impasse, but in March 1962, top NASA officials decided to choose the mode in June.

At this point, managers of the MSC resolved to sell LOR to NASA Headquarters and Marshall. They first went to Washington and convinced Dr. Joseph F. Shea, deputy director of Systems in the Office of Manned Space Flight (OMSF), and D. Brainerd Holmes, director, OMSF. Next representatives from Houston staged a day-long sales pitch in Huntsville in April 1962.

From that point until June, the behavior of Marshall Director von Braun is unclear. Stuhlinger, the chief of the Research Projects Lab, believed that von Braun preferred EOR but had become concerned that bureaucratic in-fighting would cause delays and could prevent meeting Kennedy's deadline. In the interest of promoting harmony in the Agency, Marshall's director therefore turned conciliator and favored LOR. When he announced his decision at a Center board meeting, Stuhlinger recalled, it caused a "storm" because many of his lab directors remained committed to EOR.[45]

Other evidence also suggests that von Braun was as much a wheeler-dealer as a diplomat. Headquarters officials Shea and Holmes held meetings with von Braun in May to discuss the mode options. They believed von Braun had questioned LOR mainly because he was concerned with its liabilities for Marshall. They reported later that von Braun kept asking what Marshall would gain if NASA selected LOR. Realizing that von Braun wanted his Center to branch beyond the propulsion business, Shea and Holmes offered Marshall a piece of the action on the lunar surface. Holmes later denied that a formal *quid pro quo* ever emerged, but Headquarters and von Braun discussed how Marshall could study lunar vehicles and base equipment.[46]

NASA made the mode decision on 7 June 1962 at a meeting attended by officials from the OMSF and the field centers. Formal presentations explained the modes, with Marshall engineers describing EOR. Following the presentations, von Braun said, "Gentlemen, it's been a very interesting day and I think the work we've done has been extremely good, but now I would like to tell you the position of the Center." Marshall, he then announced, supported the LOR mode. This was something of a shock to some Center personnel who had not known of his choice before the meeting.

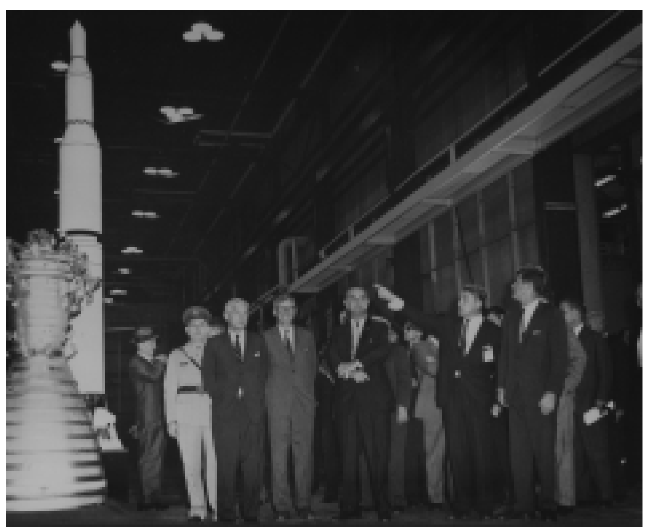
Von Braun offered technical and political reasons for supporting LOR. Admitting that he had initially been "a bit skeptical" about the plan, he recognized its engineering simplicity. LOR's light spacecraft required only one Saturn V launch and thus eliminated the need for two successful launches. Moreover, a specialized lunar craft would simplify lunar landing and launching by eliminating the need for one heavy, multipurpose spacecraft. It would smooth construction by providing for the "cleanest managerial interfaces" between centers and contractors and by reducing the amount of technical coordination. At the same time that von Braun bowed to LOR's parsimony of engineering, he acknowledged schedule pressures. The mode controversy was delaying important design decisions and construction work; unless a mode decision was made "very soon," he said, "our chances of accomplishing the first lunar expedition in this decade will fade away rapidly." Von Braun concluded that, all things considered, LOR offered "the highest confidence factor of successful accomplishment within this decade."

At the same time, von Braun also recommended that Marshall develop a crewless, automated, lunar logistics vehicle to overcome the liabilities of LOR. Launched by a second Saturn V to accompany human missions, this vehicle would expand the duration and scientific benefits of lunar missions by providing supplies, equipment, and shelter.[47]

By agreeing to LOR, Marshall got credit for being a team player. Holmes and Shea felt that von Braun's decision helped stimulate inter-Center cooperation in the Apollo Program. Shea added that the Marshall director's endorsement of LOR was "a major element in the consolidation of NASA." With its top officials united, NASA formally selected the LOR mode using a Saturn V rocket and decided to study a lunar logistics vehicle.[48] Marshall immediately began studies of the craft, and although NASA never developed a flight model, the Center eventually oversaw construction of a moon car called the lunar roving vehicle.[49]

The choice of LOR mode shaped the Apollo Program, and debates about its merits continued long afterwards. Critics of the choice complained that NASA's narrow engineering mentality led the Agency to select the cheapest means in terms of money and time and to choose excessively specialized technologies; the mode meant brief lunar visits and restricted scientific research.[50] Long after the decision, many Marshall veterans continued to echo these sentiments. Von Tiesenhausen contended that LOR helped make Apollo essentially a "dead-end." Dannenberg also believed that rejecting EOR thwarted possibilities for constructing a space station and pursuing more open-ended missions in the 1960s. Others were less negative, believing that NASA expanded the scientific utility of Apollo technology by using the third stage of the Saturn V as the basis for the *Skylab* orbital workshop.[51]

The mode episode came to an ironic conclusion when von Braun publicly defended LOR before the national media. The issue came up on 11 September 1962 when President John Kennedy visited Marshall to look over Saturn development. The President brought with him Jerome Wiesner, the



Von Braun explains Saturn hardware to President Kennedy and Vice-President Johnson during their visit to Marshall on 11 September 1962.

chair of the PSAC, Vice-President Lyndon Johnson, and NASA Administrator Webb. While standing near a Saturn I stage and with the press listening, the group began discussing the merits of LOR. Wiesner argued fervently that LOR was neither as safe nor as scientifically useful as the other modes. An angry Webb and a calm von Braun contradicted Wiesner. Kennedy listened quietly, later telling Wiesner that he too doubted LOR and that they were alone in supporting the alternatives. The argument made national headlines but quickly passed from attention with the onset of the Cuban missile crisis.[52]

The choices of the lunar mission, the end-of-decade deadline, the Saturn V, and LOR all influenced Marshall's work. NASA had a clear mission, a definite schedule, and the necessary funds. Marshall would build the Saturn launch vehicles and have plenty of resources for the task. William Sneed, a manager on the Saturn project, recalled that Marshall had cash reserves to "accommodate the unknowns and unpredictables" and to fund more than one path of technological development. James Odom said that the parallel development of critical technologies allowed Center engineers to choose the most reliable option and to stay on schedule. Robert Marshall, a Center propulsion engineer in the 1960s, summarized the meaning of the decisions: "The schedule was fixed and the performance was fixed; money was a variable. We threw money at problems." After the halcyon decade of Apollo, no Center project would have such favorable conditions; in later efforts the money was fixed and the performance and schedule became variables.[53] The challenges and resources of the Apollo Program would also cause Marshall to grow bigger and develop new skills.

Growth and Change

To develop the Saturn stages, Marshall added more personnel and built new facilities. More significantly, the enormous technical and managerial challenges led Center personnel to change their organization and culture. Werner Dahm, an aerodynamic engineer, recalled how in the 1950s ABMA had been "a single-project outfit" that worked on one vehicle at a time with a couple of major contractors. The Apollo Program changed Marshall, making it a "multiproject organization" that developed many rocket stages and space technologies, managed multiple contracts, integrated diverse technologies, and coordinated far-flung organizations. The Center adapted to its new role by strengthening its capabilities in project management and systems engineering.[54]

Of all NASA's field centers, Marshall benefited most from the free-spending era of the early 1960s. Only the expenses incurred by the MSC rivaled those at Marshall. NASA allocated funds in three categories: Administrative Operations, Research and Development, and Construction of Facilities.[55] From 1961 through 1965, Marshall's accumulated Administrative Operations obligations (comprising principally salaries) were more than double those of any other Center.[56] Marshall's accumulated Research and Development obligations through June 1968 were larger than those of any other Center, five times those of every Center except Goddard and MSC. Only MSC came close to Marshall's figure.[57]


Early 1960s test stand.

During the years in which Marshall built most of its Saturn test stands and assembly facilities, only the construction of the launch complex in Florida surpassed the Center's obligations for Construction of Facilities in Huntsville and at Michoud and the Mississippi Test Facility.[58]

Marshall was also NASA's largest contract administrator. For six consecutive years (fiscal years 1961 through 1966), Marshall let contracts totaling more than any other Center, constituting more than 30 percent of NASA's contractual obligations. In mid-1968, Marshall held (either solely or jointly with other centers) six of NASA's eight largest contracts.[59] California, Louisiana, and Alabama, the major locations of Marshall business, ranked first, third, and fourth as recipients of NASA prime contracts from fiscal years 1961 through 1968.[60]

Other yardsticks measure Marshall's extraordinary growth in the early 1960s. The Kennedy goal of reaching the Moon by the end of the decade gave the Marshall Center a virtual *carte blanche*. When NASA established Marshall in

1960, it acquired land and facilities valued at $34,651,000. Within the next four and a half years, NASA funded new facilities worth more than $125,000,000. [61] Laboratories continued to operate in buildings inherited from the Army, but the Center expanded most of them and added new facilities. Test stands for the Saturn Project consumed much of the new facility money. In June 1963, 1,200 employees moved into a modern 10-story Headquarters building. Von Braun's office on the top floor overlooked a panorama of the Alabama countryside, rimmed by hills and sloping to the Tennessee River to the south, now punctuated by monolithic test stands. The government labeled the Headquarters Building 4200, but locals often called it the "Von Braun Hilton." Behind it, two smaller buildings in the same style completed a horseshoe-shaped Headquarters complex: the Engineering and Administration Building (4201) and the Project Engineer Office Building (4202).[62]

Other than the scale of the Saturn V, nothing demonstrated more dramatically the rapid growth of the American space program than Marshall's test complex at the southern end of the Center. Visible from the small Redstone Interim Test Stand were mammoth test stands used for Saturn development: Single engine test stands, static test stands, and the huge dynamic test stands.

Marshall Center's Test Area in 1978.

The construction of new facilities led to some conflicts between the Center and labor unions.[63] Beginning in August 1960 Marshall's arsenal system triggered jurisdictional disputes between the Center's Launch Operations Directorate (LOD) at Merritt Island, Florida, and building trades unions. The unions working on Launch Complex 34 (LC–34) were accustomed to Air Force practices. They expected to install ground support equipment with little direct supervision. LOD was accustomed to the arsenal system and thought that government scientists and engineers should install some equipment and closely inspect contractors. When LOD began introducing arsenal practices, the unions quickly complained that LOD personnel were doing too much construction and supervision. In a series of brief strikes, electricians, ironworkers, and carpenters walked away from LC–34, and the project lost 800 man-days of work from August to November. The disputes culminated in November when electricians went on strike to protest LOD civil servants installing cables and consoles in the launch control center.[64]

The Center justified applying its "army philosophy" to scientific projects by defining the launch complex as a "laboratory" intimately tied to the launch vehicle, which was itself a "flying laboratory." Logically NASA engineers and scientists should install some ground support equipment as part of "research and development."[65] Von Braun insisted that scientists with Ph.Ds sometimes had to use screwdrivers and wrenches; they had to get their hands dirty to make new machinery function and to maintain expertise. Von Braun promised that routine work would be contracted out, and this policy practically eliminated conflicts at the Cape after 1960.[66]

A labor dispute in Huntsville also occurred on a facility construction project but did not involve contractor-Civil Service issues. On 14 August 1962 a dispute between unionized and non-unionized contract workers led to a strike at Marshall's Saturn V Static Test Stand. Members of the International Brotherhood of Electrical Workers formed picket lines at Marshall's entrances and over 1,200 members of other building trades unions refused to cross. Work at the test stand and several other sites ceased.[67] With the strike continuing more than a week, construction delays and attention from the national media upset Marshall managers and the Huntsville elite. Von Braun argued that the dispute was costing $1 million a day and was causing the United States space program to fall further behind the Soviet Union. The *Huntsville Times* condemned the workers for causing the United States to lose "the competition between the free world and the forces of darkness which seek to engulf us."[68] A federal injunction ended the strike on 24 August and the National Labor Relations Board convinced the electrical union to refrain from strikes and secondary boycotts.[69]

The strikes in Huntsville and at the Cape taught Marshall a lesson, and in 1963 its managers sought to forestall strikes on other facility construction projects. With assistance from the Missile Sites Labor Commission, the Center held meetings with construction unions and contractors who would build the new test facility in Mississippi. The meetings sought to resolve potential problems and secure a union promise of three years without a strike. Marshall called it "the first such conference ever sponsored by the Federal Government in advance of the award of a construction contract."[70]

During the Saturn years, Marshall opened three new facilities in Louisiana and Mississippi. All three facilities helped NASA politically, helping the Agency garner support from federal legislators from those states. The sites also had technical advantages. The Michoud Assembly Facility in eastern New Orleans, selected in August 1961 by Marshall and NASA for the manufacture of Saturn lower stages, had once been a federal plant for manufacturing Liberty ships, cargo planes, and tank engines. It had a production building with 35-foot-high rafters and a 43-acre manufacturing floor, water access via the Gulf Intracoastal Waterway, closeness to skilled labor and industrial support in New Orleans, and proximity to sparsely inhabited land that could be used as a rocket test area. [71]

Two months after selecting Michoud, NASA chose a Saturn V test site on the Pearl River in Hancock County in southwestern Mississippi. The Mississippi Test Facility perfectly combined accessibility and remoteness. Only 45 miles from Michoud by water, and with few people to relocate, its surrounding swamps were large enough so that the tremendous sound waves created during rocket firings would not cause damage.[72] Constructing test stands, rail lines, and a canal took over four years and cost over $315 million.[73] The third site, the Computer Operations Office in Slidell, Louisiana, used an unoccupied building originally owned by the Federal Aviation Administration, and began activity in 1962. Located between the assembly and test facilities, Slidell's computers supported their work in engineering, checkout, and testing.[74]

Like other facets of Marshall's development in the 1960s, the Center's personnel numbers followed the curve of Saturn development: dramatic increases in the first half of the decade, reductions later. When it opened in July 1960, Marshall inherited 4,670 employees from the ABMA. By the end of the year, Civil Service employees numbered 5,367.[75] During its first six years, the Center experienced steady growth and by the summer of 1966, employment reached a peak of 7,740. Marshall was easily the largest NASA installation with 21.7 percent of the Agency workforce.[76] Marshall's combined workforce—contractor and Civil Service—peaked at over 22,000.[77]

The establishment of Marshall forced a reevaluation of NASA's allotment of excepted and supergrade positions above the grade of GS–15. Designed to make government management appointments competitive with the private sector, these positions were "among the most potent means by which the Administrator shaped the agency."[78] NASA received permission to increase its allotment from 260 to 290 to accommodate the so-called German positions inherited from the Army, and won increases to over 700 during the Apollo buildup.[79] Marshall held as many as 56 of these positions at the height of Saturn, after which its allotment quickly dropped by a third.[80]

Marshall's workforce was predominantly white, male, and well educated. Less than one percent of Marshall employees was black. The Center did not even begin to record statistics on the number of female employees until the 1970s, when the earliest figures showed that 16 percent were women.[81] Cutbacks in the late 1960s assured that there would be little change in the composition of the Marshall workforce, since reductions hit hardest in nonengineering classifications.

The greatest changes in the character of Marshall's workforce during the first several years were an increase in scientists and engineers, and a decline in wage board personnel. The number of engineers and scientists nearly doubled within the first four years and then remained relatively constant for the next four, an increase from 27.7 to 37.6 percent of Marshall's total employment. Wage board employees declined steadily during the same period from 1,925 (35.8 percent of the workforce) to only 835 (12.0 percent).[82] Von Braun explained the trends as a reflection of "the changing role of Marshall from an essentially in-house organization to one of program management."[83]

Von Braun's explanation highlighted the major change at the Center during the Apollo period. Although Marshall continued aspects of the Army arsenal system until the cutbacks at the close of the Apollo Program, Agency policy required that the Center adopt more of an Air Force system relying on private contractors. NASA Administrator Webb and other prominent officials criticized the arsenal approach. Federal employees, they charged, were more expensive than contractor workers. Reliance on civil servants led to fixed labor costs while contractors could be laid off at the end of projects. Federal experts unnecessarily duplicated skills in the private sector. In addition to its economic weaknesses, the arsenal system had political liabilities. It localized government spending and limited the number of regions participating in the space program. Besides, Webb, a corporate lawyer, former official in the Department of Defense, and former director of the Bureau of Budget, wanted to privatize federal research and development. The Agency Administrator was also a zealous champion of using public spending to stimulate private innovation and profit.[84]

Accordingly the Center and the rest of the Agency used the Apollo Program to expand the command economy in space hardware. Since the 19th century governments had created a command economy in military technology, becoming the sole buyer of weapons too expensive for private firms to develop on their own. After the Second World War, space hardware also became command technology.[85] Military methods provided much of the contracting apparatus for NASA, but the Apollo Program was so vast and complex that the Agency had to innovate. NASA created what its administrators called a "government-industry-university team," and Marshall and the rest of the agency improved methods for running R&D organizations, "managing large systems," and supervising business-government partnerships; their managerial methods became an "unexpected payoff" of the Apollo Project.[86]

For years as part of the military, the rocket veterans who formed the core of Marshall had worked with contractors. They had worked with business and university contractors at Peenemünde, White Sands, and in Huntsville. When ABMA employees transferred to NASA, armed services procurement personnel, procedures, and practices went along. Like the military, Marshall used technical specifications, drawings, performance requirements, and incentive fees to direct contractors. Marshall and NASA also often used military quality personnel to monitor contractors and inspect parts. The Center differed from military methods of monitoring contractors in the very detailed specifications its labs produced, the rigor of its testing, and the depth of its penetration of contractors.[87]

The increasing use of contractors and growing technical complexity of Apollo led Marshall to strengthen managerial and systems engineering groups so that all the parts and participants could be integrated. In the initial organization of 1960, the Center had no systems engineering group, and the laboratories, based on the practice of automatic responsibility, collectively resolved integration problems. A small Saturn Systems Office, with its three offices for the Saturn I/IB, Saturn V, and engines, handled project management of budgets and schedules. This organization differed little from those of Peenemünde and ABMA.

But by 1962, once complicated work began on both the Saturn I and Saturn V and once contracts were let across the country, the Center's traditional organization proved unwieldy. By the middle of 1963, Marshall's workload had increased more than four-fold in three years. The fiscal year budget had grown from $377 million in 1961 to $1.07 billion in 1963. Procurement had increased almost three-fold in three years, from $315.5 million to $949.7 million. The flood of responsibility swamped the Saturn Systems Office and the labs. Center officials worried that a lack of central controls could lead to excessive changes, cost overruns, and schedule slips.

By 1962 von Braun moved to forestall any problems. He told a management conference that his rocket team had changed from being a research and development organization to also being "a managerial group." To adapt, he oversaw a reorganization in 1962 that gave more authority to managers of a project (a "project" in NASA parlance was a discreet technology that was part of a larger "program"). Justifying the change in a three-page memo, "MSFC Management Policy Number 1," he explained that multiple projects necessitated stronger project offices. The labs would still be organized by technical discipline. Now, however, project offices would coordinate plans, assignments, and budgets for work involving more than one lab, and would oversee technical staff directly assigned to project work.

A major reorganization of the Center on 1 September 1963 formalized the new arrangements. One organizational branch called Research and Development Operations contained the labs, and another equal branch called Industrial Operations contained the project offices. In the Center hierarchy, lab directors and project managers were on an equal organizational rung for the first time. Within various projects, the project offices managed and the labs provided support. In addition, each lab had a Saturn Project Engineering Office to coordinate activities with the Saturn Project Office.[88]

Moreover, Marshall enhanced its abilities to handle integration problems. Pulling together the designs and hardware of the many pieces of a multistage vehicle was an enormously complex task. NASA had to help pioneer the relatively new field of systems engineering, and Marshall was in the forefront. In 1962 the Center established a Saturn/Apollo Systems Integration Office for working with other NASA centers. Marshall also enlisted a systems engineering contractor; Boeing, the contractor for the Saturn V first stage, became the

Saturn V Systems Engineering and Integration contractor. NASA and Marshall adopted similar practices for the Shuttle and later projects.[89]

After this reorganization, the project offices and labs acted as checks-and-balance on one another. Checks-and-balances were “built-in,” Lucas recalled, because the labs and project offices had different interests. Scientists and engineers in the laboratories wanted to be thorough and inventive, and wanted the job done right with little concern about cost, schedule, or administrative nicety. In contrast, project offices were responsible for getting the job done on time and within budget. To meet deadlines and budgets, project managers sometimes had to limit technical innovations. Nonetheless the project offices, James remembered, did not make technical decisions based on managerial standards; they relied on “change boards” composed of lab experts who studied each proposed innovation and determined whether it was necessary. He also said that von Braun wanted to base hardware decisions on their technical merits rather than schedule or cost. Von Braun told James that “when you have an argument with the laboratories, I want you to know that I am on their side.”[90]

As Saturn development progressed, Marshall hired more experienced project managers and pioneered new oversight methods. In 1964 the Center acquired on temporary assignment over a dozen Air Force officers who were veterans in running big, expensive, and complex aerospace projects; they had skills in budgets and schedules, and systems management. Also in 1964 Air Force General Edmund O’Connor became director of Industrial Operations, serving in that post throughout most of the Saturn years.[91]

The Saturn V Program Office, headed by Peenemünde veteran Arthur Rudolph, oversaw the crucial Apollo activities of the Center and its contractors. The office ensured that Saturn manufacturing stayed within budgetary and schedule guidelines and that all the contractors and components fit together in one system. This was an enormous problem because Marshall oversaw contracts with hundreds of companies in dozens of states. Rudolph thought his major problem was that “in a big program like the Saturn V you have many people involved and usually people want to go off on tangents,” and so he tried to “get them all to sing from the same sheet of music.” Saturn’s self-styled “choir director” oversaw regular meetings in which Marshall and contractor officials reviewed and revised plans as the program evolved; sometimes the meetings would last until well after midnight.[92]

One novel feature of the Saturn V Program Office was a room called the Program Control Center. Rudolph's staff designed the room to enhance "visibility" and reveal problems. Three thousand square feet of visual aids and scheduling charts papered its walls. Based on systems developed for military missile programs, the charts graphed a path of progress for each part and showed crucial schedule checkpoints. Information for the charts passed up the Center-contractor organization, with each manager relaying data through superiors. Each chart directed attention to parts that were lagging so that managers could invest more resources on these critical parts.

Marshall officials were careful in how they used the charts. They sometimes regarded them as a "gigo" system—garbage in, garbage out—knowing that managers sometimes withheld information or exaggerated progress. James, Rudolph's successor as Saturn V manager, believed that Rudolph sometimes pretended that he could not understand the charts, using this pretext to question project managers about their progress. In remarks to Congress in 1967, Rudolph admitted schedules were often "soft" and could be set back. Nonetheless he thought the charts and schedule deadlines were useful managerial tools; in his words the "visibility" enforced "discipline" and got rid of "looseness." More importantly, the charts helped officials integrate the work of the Saturn team. NASA Administrator Webb loved the Program Control Center and its management charts. Webb brought dignitaries to Marshall just to parade them through the room which he said was "one of the most sophisticated forms of organized human effort" that he had "ever seen anywhere." When Webb looked at the charts, Saturn Program Control Manager Bill Sneed said, NASA's Administrator recognized that Marshall was doing more than building a lunar rocket; the Center was "innovating and developing management systems" that were "the best known to man."[93]

Marshall also worked with the rest of NASA to coordinate work on Apollo. Headquarters had an Apollo program office that made plans, allocated and monitored resources, set schedules, and maintained oversight of specifications and standards. A NASA Management Council, composed of top Headquarters officials and field Center directors, set broad policy. On technical issues, however, the centers had considerable autonomy. Experts from the centers staffed eight Inter-Center Coordination Panels on crew safety, instrumentation and communications, flight mechanics, flight evaluation, electrical systems, launch operations, mechanical design, and flight control operations. In this way experts assumed daily responsibility for coordination. Generally, these decentralized panels resolved disagreements, but difficult issues passed up the line to a Management Review Board composed of Headquarters officials Center directors, and program and project managers. The Centers and Headquarters also established a mirror organization, with functional offices matching each other to facilitate communication.[94]

Kurt Debus, Wernher von Braun, and Eberhard Rees watch the SA–8 launch in May 1965.

Headquarters also hired a systems engineering contractor to help it monitor the technical activities of the field centers. BellComm, a subsidiary of AT&T, helped review and define systems requirements, missions, tests, and quality programs. Both Marshall and the MSC complained about BellComm's role, questioning the legality of the company's access to proprietary information from other contractors and doubting the wisdom of duplicating expertise at the field centers. More importantly, both Marshall and Houston objected to micromanagement from Washington. Von Braun argued at a NASA Management Conference that there were "too many nuts and bolts engineers in Washington and too few managers" and that Headquarters wasted resources on "petty supervision" and efforts to "second guess" the centers. Nevertheless, Headquarters maintained a strong program office, and Shea, deputy director of Systems in the OMSF, defended the BellComm contract as "good insurance" that would proceed "regardless of Centers' wishes."[95]

Disagreements aside, the arrangements helped NASA smoothly coordinate Apollo activities. Such harmony contrasted with the planning controversies early in the program and on later projects. Technical and organizational factors also contributed to intercenter cooperation.

Marshall worked well with the MSC during the Apollo Program mainly due to technical factors. For Apollo, MSC and Marshall had a clear division of labor. Houston built the spacecraft and Huntsville built the launch vehicle, and one sat on top of the other. Interfaces between spacecraft and launch vehicle were clean and simple, mainly a matter of connecting wires and bolts. Disputes mainly resulted over weight; Marshall believed that Houston's spacecraft was too heavy while Houston thought Marshall's launch vehicle was too heavy. Von Braun credited the resolution of problems like this to mutual respect by the Centers and the unsung work of the intercenter panels.[96]

Social and technical factors helped Marshall work well with the Kennedy Space Center at Cape Canaveral. NASA's launch facility had originally been ABMA's Missile Firing Laboratory. When the Army rocketeers transferred to NASA, the lab remained under Marshall's organization as the Launch Operations Directorate. Kurt Debus, the launch team's director, had been von Braun's assistant at Peenemünde and Huntsville, and many members of the launch group continued to work in Huntsville. Alabama and Florida personnel worked closely together to ensure the compatibility of the assembly and launch facilities with the launch vehicles. Huntsville personnel helped design and construct some of the Cape's launch facilities.

By 1962, organizational problems emerged that led NASA to make the Launch Operations Directorate into an independent Center. Debus and von Braun worried about the managerial liabilities of having the launch team report to Marshall. Particularly problematic was the possibility that the launch team would have to arbitrate disputes between Marshall and another NASA Center. To solve these problems, NASA decided to make the launch team into an independent field center. Although Huntsville officials had lively debates about the merits of being a rocket "developer" or "operator," von Braun supported the change. On 1 July 1962 Marshall's launch laboratory became the Launch Operations Center, and, after President Kennedy's assassination, it became the Kennedy Space Center.[97]

The Apollo Program then led to changes at the Marshall Center in the 1960s. Apollo resources and challenges allowed Marshall to enhance its in-house research and development capabilities by adding new personnel and facilities. At the same time the Center modified its research organization and culture by adding new mechanisms and expertise in contractor management and systems engineering. Together the adaptations helped Marshall solve the enormous technical challenges of the Saturn launch vehicles.

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