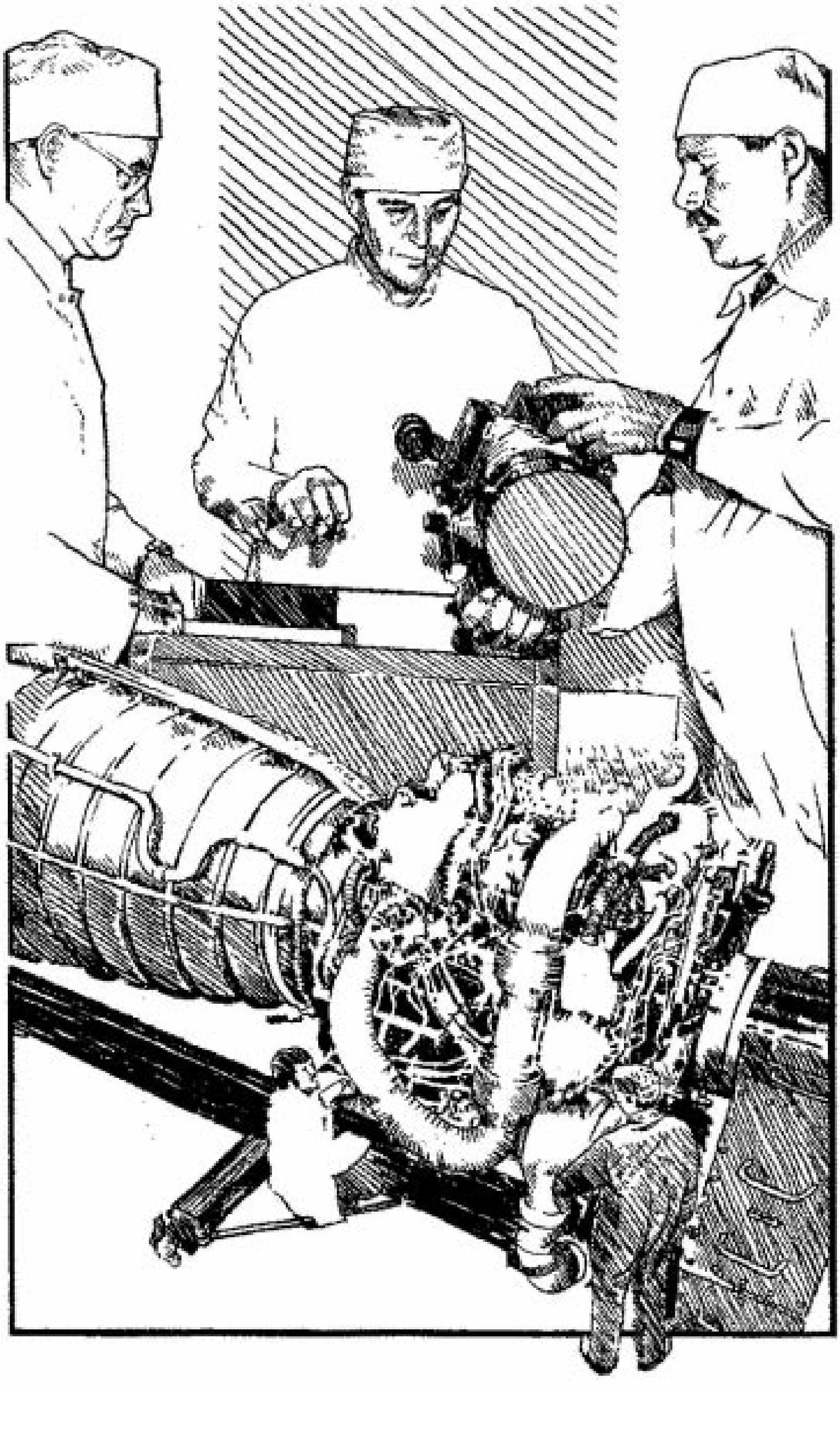

CHAPTER 8: A Contractual Relationship

Through its NASA contracts, the United States Government mobilized a large segment of American industry comparable to that ordinarily achieved only during the exigencies of war. Space, and more specifically the Apollo lunar program, required a massive effort by a fledgling aerospace industry still struggling to find its own identity. NASA grew massively in size and changed markedly in its configuration from a NACA-like and largely passive research organization into a research/development and mission-oriented agency whose primary business became project management and systems engineering. NASA engineers, trained and with experience in the laboratory and test facility, became managers of people. Whereas in war the government generally mobilized the Nation's resources through conscription, regimentation, and regulation, NASA mobilized the aerospace industry through a contractual relationship.

Arnold S. Levine in *Managing NASA in the Apollo Era* attributes the enormous increase in government contracting after World War II to the basic virtues of contracting out to the private sector, the limitations of formal advertising, and the demand for special skills in the management and integration of complex weapons systems. Contracting allowed the government to tap the technical experience and capabilities available in the private sector, which was not bound by civil service hiring and retention regulations—albeit labor legislation and union contracts certainly had an effect. Moreover, contracting allowed a very real flexibility in work force and budget expenditures.[1] While the government required it, the reality was that through contracting, NASA built a strong and diverse supporting political framework for government-funded space-related programs, and concurrently helped develop a broad-based technological strength throughout the national economy.

NASA's contracting drew on both the Air Force's heavy reliance on independent contractors for design and delivery and the Army's traditional arsenal or in-house production and design capability. NASA engineers, at least through the Apollo years, maintained an in-house capability allowing them to keep the design and technical skills to effectively direct, lead, and manage the NASA contractors.[2] Thus, the NASA-contractor relationship could best be defined as a partnership rather than a customer-client relationship.

Willard F. Rockwell, Chief Executive of North American Rockwell, described the contractors as the "unsung heroes of the Apollo program." Space programs altered the character of the private sector of the old aircraft industry and changed the traditional relationships between government and the private sector. North American Aviation, for example, founded in 1928, merged with Rockwell-Standard Corporation, an automotive parts manufacturer, to become North American Rockwell Corporation, a major aerospace firm and the prime contractor for the Apollo space vehicle.[3] North American and NASA's many contractors became more than suppliers or manufacturers of space components; they became "cooperators" with government and other firms in the design, development and assembly of spacecraft.

North American figured prominently in NASA's Apollo lunar effort. An understanding of North American's relationship as a contractor to the MSC offers an illuminating insight into the basic nature of NASA's Apollo program and its management. It also provides a study of the dynamics of American industry and of the relationships of industry to government.

John W. Paup, North American's program manager for Apollo, returned to work for North American's Space and Information Systems Division in 1961 following a stint with Sperry Rand Corporation. His initial job, working under the Division President Harrison A. "Stormy" Storms, was to oversee North American's proposal to NASA to design and construct the Apollo spacecraft. J. Leland (Lee) Atwood, president of the corporation, had reorganized North American's Missile Division as the Space and Information Systems Division the previous year. NASA selected North American's Rocketdyne Division, under Samuel K. Hoffman, to be the primary contractor for each of the Saturn propulsion systems under the management of the Marshall Space Flight Center. In November 1961, North American's Space and Information Systems Division received the Apollo spacecraft contract administered by MSC. North American became the only company with hardware in every part of the Apollo "stack," including the command module, service module, lunar module, instrument unit, launch escape system, and first, second and third stages of the Saturn rocket.[4]

A NASA contract involved some tensions between the Agency and the contractor in that the manufacturer naturally desired to maximize profits. The manufacture of space components required man-rated production quality, redundancies, and to an extent the sublimation of costs to quality and assurance. That plus the cooperational aspects of production were new experiences for industry. Although cost-plus-fixed-fee and special incentive contracts ameliorated the basic conflict of interests between the producer (the contractor) and the consumer (NASA), there would, of course, be no perfect solution.

A more basic communications problem also pervaded the contracting relationship. Contractors changed from program to program and project to project. Their knowledge and experience, as a result, tended to be very limited and defined. John Paup explained that "Government is the customer. The contractor is the producer. The experience that had been gained in building spacecraft in Mercury, and subsequently in Gemini, was known to the customer; it was not as well known to the contractor." But, he said, the contractor had more and better experience in handling "the magnitude of the Apollo program." Thus the government, he said, possessed the technical and operational knowledge, but the "real live program knowledge" was best known by the contractor.[5] Managing the Apollo program required fusing the knowledge and energies of diverse and traditionally competitive firms to produce a product that no one of them could independently produce. NASA management, contractors and subcontractors were indispensable to each other and to the program.

Program management required close communications and coordination between NASA Headquarters and centers, and between the project or program managers at the center level and the contractors. Effective management required overcoming, or at least subordinating, the independent and competitive instincts of cooperating firms. The contractor-subcontractor relationship provided an effective vehicle for doing that. Systems engineering and NASA contracting, however, confronted an inherent cultural tension within the engineering design/manufacturing relationship.

North American Aviation began in 1928 during the height of the 1920's stock market boom as an investment holding company headed by Clement N. Keys. North American bought interests in Curtiss Aeroplane and Motor, Transcontinental Air Transport, Curtiss Flying Service, and Douglas Aircraft. It acquired all of Eastern Air Transport, 27 percent of Transcontinental, and 5 percent of Western Air Express, and invested in Sperry Gyroscope, Ford Instruments, Intercontinental Aviation, and Berliner-Joyce Aircraft. General Motors acquired control of North American in 1933 when Ernest R. Breech became Chairman of the Board. General Motors merged its Fokker Corporation of America with North American's Berliner-Joyce to establish General Aviation Corporation which for the first time brought North American directly into aviation manufacture.

When the Air Mail Act of 1934 required the separation of aircraft manufacture and airline operations, North American was made a separate manufacturing concern headed by J.H. Kindleberger, and airline operations were consolidated as Eastern Airlines under Eddie Rickenbacker. General Motors sold its interest in North American in 1948. John Leland "Lee" Atwood became president, and Kindleberger became North American board chairman. By 1964, North American's $2 billion annual income derived heavily from government contracts associated largely with Apollo, Saturn S-II, and Minuteman production. North American Aviation merged in 1967 with Rockwell-Standard Corporation, a major producer of automotive parts, to become North American Rockwell Corporation. John R. Moore, previously the executive vice president for North American, headed the new corporation called the Aerospace and Systems Group, of which the North American Aircraft Division remained a component. Subsequently, the corporation became Rockwell International Corporation.

The command module mockup under construction by North American Aviation at Downey, California, shows the more spacious three-person interior of the Apollo spacecraft.

Source: Russ Murray, *Lee Atwood . . . Dean of Aerospace* (Downey, California: Rockwell International Corporation, 1980).

The "manufacturing people build from the details up. Engineers design from the top down." The engineer formulates a basic design first and then proceeds to the detailed design of the pieces. The manufacturer, on the other hand, wants detailed design on the little pieces first so that it can plan and design the tools to produce the many parts of the whole. In some respects, the development of a spacecraft was something like creating a continually growing and changing organism where each part could affect the nature of the whole system. Inasmuch as each part, as well as the whole system, was going through constant design, test, and evaluation, the "problem of making schedule, dollars and performance come out acceptably" was brought sharply into focus on the Apollo program.[6] Communications, or knowledge transfer, was a fundamental necessity of the system. It had to occur within each center between the program and project offices and the line divisions, from center to center, and between the center and headquarters. The contract manager at the center then became the agent for technology and information transfer between NASA and the contractor. But it was also critical that the learning experiences and technology of one space program were transferred to the next.

To help facilitate that transfer, Dr. George E. Mueller (who became NASA's Deputy Associate Administrator for Manned Space Flight in 1963) organized the Gemini-Apollo Executives group in 1964. The idea was to facilitate the transfer of information and experiences from the Gemini program to the Apollo program. The need was very real. Apollo contractors were trying to reinvent the wheel that had already been invented by Gemini contractors, thus the Apollo program in 1964 had fallen 6 months behind schedule and costs were spiraling. John F. Yardley, McDonnell Aircraft Company's manager for Cape operations, said that the immediate result of that Gemini-Apollo Executives meeting was to finish the program 2 months ahead of schedule and save large sums of money for the government and the contractors.[7] Those savings were effected largely by eliminating a duplication of effort among contractors, by sharing the expertise or "how-to" between contractors, and simply by facilitating the transfer of NASA's experience to the private sector. Meetings were held periodically through the following years.

At the conclusion of the Gemini program, Gemini and Apollo executives met on January 27, 1967, for a "final review" of Gemini, with an agenda to review the "lessons learned" from Gemini that would benefit Apollo. That same day President Lyndon B. Johnson signed the world's first space treaty. And at noon of that same day, Virgil Grissom, Edward White, and Roger Chaffee boarded Apollo spacecraft 012 (AS-204) for launch simulation tests. That afternoon, as the tests at Cape Kennedy progressed, in Washington, D.C., President Johnson addressed the Ambassadors of Great Britain and the Soviet Union, high American officials, and representatives from 57 foreign nations on the occasion of the signing of the international treaty committing those nations to the peaceful use of space and prohibiting weapons of war in outer space. Johnson said, "This is an inspiring moment in the history of the human race." Later that afternoon, tragedy struck. News of the Apollo 204 fire, Lyndon Johnson said, "hit me like a physical blow."[8] The news struck the Gemini-Apollo Executives no less forcefully.

In the separate meeting which began that morning and was scheduled to run through the 28th, the business executives whose companies built the Gemini and Apollo systems were discussing: "How do we assure that the maximum transfer of recorded experience from Gemini to Apollo takes place?" Yardley summarized for his counterparts in the Apollo program McDonnell's Gemini experiences so that "our Nation's space program can make the best use of our collective knowledge." But he noted that McDonnell was not closely involved with Apollo and had little knowledge of where the program stood or what practices were being used.[9]

One of the greatest construction difficulties with Gemini, he recalled, was related to the "weight critical" configuration of Gemini. This resulted in launch delays, lengthy retest periods following modifications, and a lower level of reliability than desired. Modular construction, on the other hand, facilitated the testing of each independent module without researching an entire system. And the interface between modules was kept as simple as possible. In contrast to Mercury's "layered" construction, Yardley explained, each Gemini unit had to be individually accessible and individually removable. We learned too that aircraft construction techniques did not meet spacecraft requirements, and as a result Gemini "pioneered in a number of areas such as all brazed propulsion system plumbing, crimped electrical connections, salt-free coldplate brazing, etc." McDonnell learned too that product and design changes were inevitably required as a result of testing and flight operations. It was necessary for McDonnell or any manufacturer to participate heavily in flight operations in order to close the response time for necessary modifications. It was also critical to incorporate changes with test operations, that is, to modify testing and evaluation procedures to accommodate the changes. All of this required close coordination between the manufacturer and test personnel. The management tool used, Yardley noted, was daily meetings at the "most detailed level between all organizational elements."[10] Space manufacture required an unusual degree of integration and cooperation between government and business and between ordinarily independent and often competitive private firms. Changing technology created changing social structures, and those changing structures facilitated yet more advances in technology.

The independent and competitive nature of American corporations, and particularly those in the developing aerospace-related industries, traditionally tended to preclude cooperation and the flow of technical knowledge from one to the other. This is, incidentally, one reason why managing engineers and executives such as John Paup, John Yardley, Robert Seamans, Jim Elms, and George Mueller, among many others, tended to move with some frequency from one corporation to another or from government to corporations. The exchange or transfer of managers allowed a transfer of knowledge otherwise discouraged by the competitive nature of the corporate world. The experiences of John Paup and North American Aviation are representative of those in the industry, and illustrate the growth and maturation of the aerospace industry.

John Paup, who as previously mentioned went to North American's Space and Information Systems Division from Sperry Rand in 1961, joined Milton Sherman, Charlie Feltz, and Norman Ryker (all of whom had X-15 or Jet Propulsion Laboratory contract experience) in developing North American's proposal for an Apollo spacecraft. The Apollo program and the contractor relationship to NASA began well before President John F. Kennedy established a lunar landing as an Apollo goal. NASA held an industry conference on July 29, 1960, to announce and describe the parameters of the Apollo program as it then existed. Potential bidders then met at Langley where they were briefed by Bob Gilruth and members of the Space Task Group. Subsequently, NASA awarded independent feasibility study contracts to General Dynamics, General Electric, and Martin Company; and from these studies and in-house work, NASA developed the Request for Proposal (RFP) which included a statement describing the nature and specifications of the work. North American received the RFP in July. One hundred North American engineers worked on the three-volume proposal which was delivered before the October 9, 1960, deadline. Next, Paup, with Company President Leland Atwood, Division President Harrison Storms, and others conducted an oral briefing on the North American proposal at the Chamberlin Hotel at Point Comfort, Virginia, in competition with teams from Convair, General Dynamics, General Electric, Lockheed, Grumman, and other prospective contractors.[11] The competition was itself a historic occasion. Paup recalled later:

> . . . this was undoubtedly the biggest procurement the government had ever considered and it was the first wide open big competition that NASA had ever run. So, there was a lot of bigness to this proposal activity—the trade journals were full of it, and much publicity was given to such an exploration. The whole idea of going to the Moon, of course, was a big thing. But, moreover, it required a big business operation. Everybody concerned with, or that speculates in big business, really had been waiting to have something like this to talk about for a long time.[12]

The North American delegation from Downey, California, traveled to the briefing in two separate aircraft, Paup remembered, to minimize a "possible catastrophe to our effort." But after reaching Washington, D.C., safely, the combined delegation boarded another plane for the trip to Langley only to be forced to circle for an interminable time because of bad weather. Finally, with about 10 minutes to spare, they made their meeting—only then to be stymied by the fact that the hotel's electrical plugs did not match their projection equipment. Finally, he said, Milt Sherman "took out his pen knife, cut the plug off, peeled back the wires, and sat there all during the briefing" holding the two bare electrical wires into the connections. "Our reliability was assured by man, not by any system or mechanism or planning—maybe that's a message for the Moon program," he added.[13]

The announced major elements of the Apollo-Saturn program included the design and construction of the spacecraft, the launch vehicle, launch facilities, control centers, and tracking network facilities. The spacecraft project itself, for which North American competed against four other bidders, comprised a command module which housed the crew and would be the only part of the vehicle to reenter the atmosphere and land, a service module which would include a propulsion system to return from the Moon but would not itself descend to Earth, and a lunar landing module which included propulsion systems for decelerating and landing on the Moon. A contract for the lunar landing module was to be awarded to a subcontractor at a later date. The contract envisioned the launch of the Apollo spacecraft by a NOVA-type rocket (not yet designed) using a direct lunar approach, or possibly a spacecraft launch and direct return.[14] The options of a lunar orbit rendezvous and the Saturn V propulsion system (with approximately 65 percent of the thrust of the envisioned NOVA rocket) were at first largely ignored, but would later be reinstated as part of the program.

That decision, coming almost 2 years after the initiation of the Apollo work, changed the configuration of the spacecraft.

Once the contractor presentations were completed, a NASA Source Evaluation Board, chaired by Max Faget and including Robert Gilruth, Robert O. Piland, Wesley Hjornevik, Kenneth S. Kleinknecht, Charles W. Mathews, James A. Chamberlin, and Dave W. Lang from MSC, George M. Low, A.A. Clagett, and James T. Koppenhaver from Headquarters, and Oswald H. Lange from the Marshall Space Flight Center, began the meticulous and intensive work of evaluating the proposals. Some 190 persons representing all major elements of NASA and a few representatives from the Department of Defense reviewed the proposals and made independent reports to the Source Evaluation Board. The Board divided itself into subcommittees, assisted by panels of specialists, and submitted evaluations based on a weighted scale of 30 points for the technical qualifications of the proposal, 30 points for the technical approach, and 40 points for business management and cost factors.[15]

Of the five competing contractors, General Electric proposed to collaborate with Douglas Aircraft, Grumman Aircraft, and Space Technology Laboratories. McDonnell proposed to team with Chance-Vought, Lockheed, and Hughes Aircraft. General Dynamics proposed to work with AVCO. The Martin Company and North American proposed to work as prime contractors and subcontract specific components of the work. The Source Evaluation Board then submitted its analysis and very close summary ratings (6.4 to 6.9 for the 5 proposals on a scale of 0 to 10) to the Administrator for a final decision.[16]

On November 28, North American, which the media had not considered a major contender, received word that it had been awarded the NASA Apollo contract. The decision rested in part on the greater attraction of dealing with a single primary contractor as opposed to a consortium of contractors. What followed in those first 6 months of "getting to know you" and getting organized was an intense effort to resolve unanswered questions and issues within North American and between North American and MSC representatives who would manage the $934 million contract. "Problems," Paup said, "came at us wave, after wave, after wave. The days were long, the excitement was intense, and the period was wonderful from the point of view of participating. But nevertheless they were tiring and exhausting days."[17] And then the honeymoon ended, and the hard, unceasing work began.

In December 1960, North American's Space and Information Systems Division signed on its first four major Apollo subcontractors. Collins Radio would manage the spacecraft telecommunications systems. Garrett Corporation's Air Research Division would handle environmental control equipment. Honeywell, Incorporated contracted with North American to develop the stabilization and control system, and Northrop Corporation's Ventura Division was assigned the parachute Earth landing work—later abandoned by NASA. NASA subsequently selected General Electric to oversee the integration of the Apollo space vehicle with the launch vehicle and to assure system reliability. North American then signed up the Marquardt Corporation to build the reaction-control rocket engines for the spacecraft, Aerojet-General to develop the service module propulsion system, Pratt and Whitney to build the Apollo fuel cell, and AVCO Corporation to design and install heat resistant (ablative) material on the spacecraft's outer surface. Over the next few years, numerous subcontractors went to work for North American's Space and Information Systems Division on Apollo hardware and design.[18] The North American prime contract thus became an umbrella contract creating a consortium of firms to accomplish a task that no one of them singly could complete.

No one had previously designed and built a vehicle to carry men to the Moon and back. There were, to be sure, ongoing Mercury (and by 1964) Gemini experiences to draw upon, but Apollo was different. Just as North American and MSC managers began to get their organization and efforts in focus, the work changed rather significantly. On July 11, 1962, now a year and a half into the Apollo spacecraft work, NASA announced that instead of building a spacecraft that would make a descent onto the surface of the Moon from an Earth launch or from Earth orbit (as envisioned in the original design concept), a lunar excursion module (LEM) separated from a command module in a lunar orbit would make the descent. The decision required major design changes in the lunar spacecraft and in the design and construction of the LEM, the inclusion of new rendezvous and docking apparatus, and new tests and procedures for every component. It also resulted in the award of a prime contract for the LEM to Grumman Corporation. Grumman and North American engineers held their first meeting to discuss the design of the LEM and its interface with the Apollo spacecraft on January 14, 1963.[19]

The lunar-orbit-rendezvous (LOR) decision was itself a critical historic moment in the Apollo-Saturn program. Engineers first preferred the direct ascent NOVA rocket technique “pictured in science fiction novels and Hollywood movies.” But the technical realities and cost of such a battleship-sized, fuel consuming monstrosity led to the Earth orbit option. Advanced Saturn rockets, already in production, could launch a vehicle into Earth orbit from which a lunar mission vehicle could be launched and docked on its return. Once the NOVA rocket was rejected, NASA engineers, particularly those at MSC and Marshall Space Flight Center, supported the Earth-orbit-rendezvous (EOR) concept, in part because it obviously would be a prototype for a permanent space station.[20] But neither option was selected.

Serious study of LOR possibilities began at Langley Research Center in the Lunar Mission Steering Group, led by Clinton E. Brown who headed Langley’s Theoretical Mechanics Division, and in a special Rendezvous Committee, chaired by Dr. John C. Houbolt who was assistant chief of the Dynamic Loads Division. William H. Michael, Jr., a member of Brown’s study group, produced a monograph describing the advantage of parking the Earth-return propulsion part of a lunar spacecraft in orbit around the Moon during a lunar landing mission. Chris Kraft commented later that he thought this study became the seminal piece in the LOR decision. In 1960, Houbolt, with Ralph W. Stone, Clinton E. Brown, John D. Bird and Max C. Kurbjun, formally submitted a report to associate administrator Robert Seamans advising the LOR concept for the proposed Apollo program. Strong objections within NASA, however, centered on the proposition that the development of problems in a lunar orbit would be far more unsolvable and hazardous to the astronauts than would be problems in an Earth orbit.[21] Thus the lunar orbit concept remained dormant and discounted.

John Houbolt, however, refused to let the issue lie. In November 1961 in a private nine-page letter to Seamans, he bypassed the NASA hierarchy which was overwhelmingly indisposed to the lunar orbit concept. “I fully realize that contacting you in this manner is somewhat unorthodox,” he admitted, “but the issues at stake are crucial enough to us all that an unusual course is warranted.” Seamans responded 2 weeks later to the effect that new studies of that option would be initiated. Although Houbolt remained a pariah in the NASA

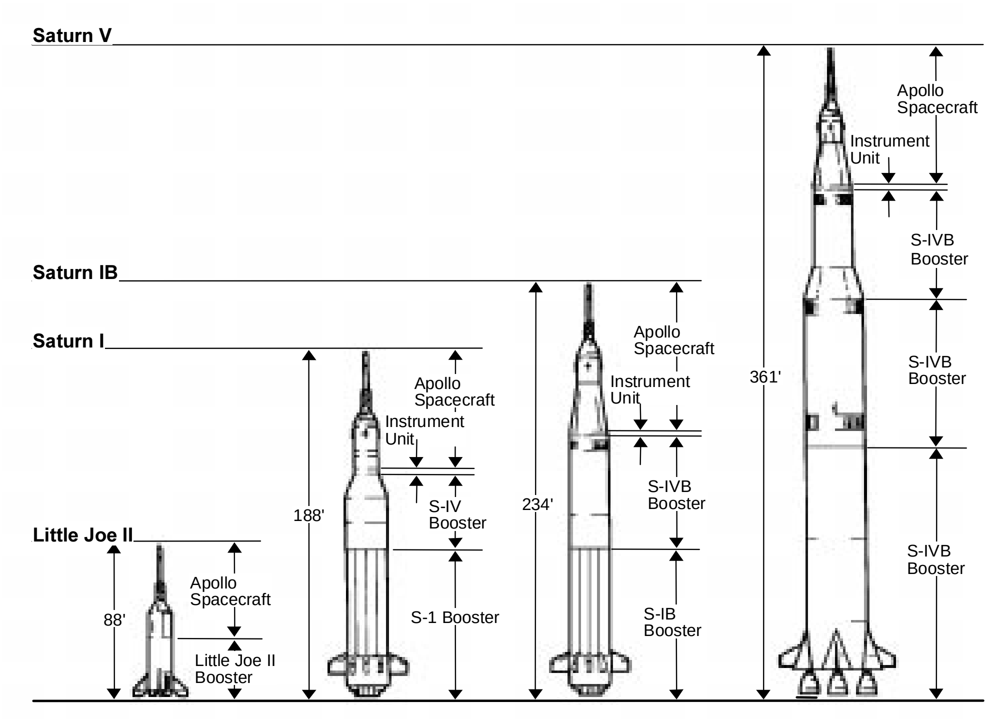

FIGURE 8. The Apollo Stack

community for some time, new tests and analyses did support the LOR over the EOR technique. Subsequently, Bob Gilruth and MSC personnel shifted to the LOR approach, and they were soon joined by Wernher von Braun's engineers in Huntsville. Gilruth and Von Braun, with their engineers, then persuaded James Webb and other administrators to support LOR. President Kennedy's science advisor, Jerome Wiesner, however, continued to oppose the lunar rendezvous. Nevertheless, on July 11, 1962, long after work on the Apollo spacecraft had begun, Webb and Seamans announced during a press conference that the projected lunar mission would employ a lunar orbit approach.[22] As previously mentioned, it meant considerable retooling, redirecting, and retesting for Apollo-Saturn contractors.

Instead of lengthening the time frame for the lunar mission, the Houbolt decision probably put NASA and its contractors back on track, and ultimately resulted in saving time and money. A NOVA rocket, many believed, required far greater power, fuel, and money. The Houbolt decision meant that existing technology and equipment could be better applied in the lunar landing program. For example, the decision was reached in August 1962 that the Apollo command module could use Rocketdyne engines being developed for the Gemini spacecraft, rather than requiring newly designed engines as projected originally.[23] Most importantly, the lunar approach championed by Houbolt proved eminently successful.

Engineers made a number of other critical engineering and design decisions in 1963 and 1964. For example the virtual impossibility of accurately measuring fuel masses in a zero-gravity environment was in part solved by measuring the radioactive particle emissions from the propellant. The final resolution involved the use of a capacitants system for the service module propellents. Heat shield problems were solved by using an open-faced fiberglass honeycomb filled with ablative material. In February 1964, NASA decided to reject the planned land recovery of the Apollo spacecraft after exhaustive tests and design and weight problems ruled out a paraglide landing system. NASA elected to use parachutes and a water landing as used with Mercury and ultimately Gemini. The development of long-endurance and restartable fuel cells by Pratt and Whitney engineers resolved many of the weight, electrical and power problems in the spacecraft. Although the production of what became known as the Block I command module continued and would be used in initial Apollo-Saturn test flights, design of the Block II module, which included lunar orbit qualifications and the LEM configuration, was approved in November 1964, and construction on it began immediately under a new North American Apollo program manager, Dale D. Myers. (Later, in 1970, Myers left industry and served with the Department of Energy before replacing George Mueller in NASA's Office of Manned Space Flight to head the space shuttle program.)[24] As the work developed and became more focused, NASA added more contractors, and primary contractors, such as North American, used more subcontractors.

North American recruited subcontractors in much the same fashion as did NASA. It issued RFPs, established source selection boards, adopted a point rating system (similar to a system North American previously used on its F-108 fighter and B-70 bomber contracts), and submitted the recommendations to the North American Source Selection Board which made the final determination for all subcontracts.[25] North American's major Apollo subcontractors are listed in table 4.

NASA contracts and subcontracts attracted enormous public attention and competition. And those who received the contracts worked, as did the astronauts and NASA engineers, under the public eye, or as Gilruth put it, they pursued "life in a goldfish bowl."

Noticeably, and perhaps expectedly, members of Congress also kept a keen eye on the award and placement of NASA contracts. Administrator Webb particularly worked under the gaze of Congress. MSC personnel did so as well—but to a lesser degree. Texas' congressional delegation, and notably Olin E. Teague, who chaired the powerful NASA Oversight Subcommittee of the House Committee on Science and Astronautics, maintained a constant vigil on the award of the greater and lesser NASA contracts and on the subcontracts let by the primary contractors—particularly those in Texas. Teague, as did other Congressmen, received annual status reports on NASA contract awards from NASA's Financial Management Division. Those reports identified the contract recipient by firm, city, county, total number of contracts received, and dollar value of the award. At the close of 1967, for example, Texas contractors and universities received a total of $866,571,000 in NASA contracts and grants, of which the larger portion ($643.5 million) went to Houston firms. Texas-based contractors and those firms with large divisions physically located in Texas with NASA contracts in excess of $100 million included IBM, General Electric, Philco Ford in Houston, and LTV Aerospace in Dallas. Teague also maintained independent contact with many primary and small contractors and frequently requested and received financial data from Administrator Webb as well as from many of the primary contractors. His office, judging by his correspondence, became something of a clearinghouse between many prospective NASA contractors and the Agency.[26]

TABLE 4. Major Apollo Subcontractors
(contracts in excess of $1 million)

Company	System	Approx. Value as of April 1966 (in millions of dollars)
Accessory Products Company Whittier, California	Helium transfer unit, valves, and assemblies	$ 2.2
Aerojet-General Corporation Space Propulsion Division Sacramento, California	Service module propulsion motor	62.6
Aeronca Manufacturing Company Middletown, Ohio	Honeycomb panels	12.5
Amecom Division College Park, Maryland	C-band and S-band antennae	1.4
Applied Electronics Corporation of New Jersey, Metuchen, New Jersey	Pulse code modulation systems	1.0
AVCO Corporation Research & Advanced Development Division, Willington, Massachusetts	Ablative heat shield	30.0
Beech Aircraft Corporation Wichita, Kansas	Supercritical gas storage system	19.2
Bell Aerosystems Company Buffalo, New York	Positive expulsion tanks for reaction control system	10.1
Beckman Instruments, Inc. Fullerton, California	Data acquisition equipment	2.7
Collins Radio Company Cedar Rapids, Iowa	Communications and data	88.2
Control Data Corporation Government Systems Division Minneapolis, Minnesota	Digital test command system	9.4
Cosmodyne Corporation Torrance, California	Liquid hydrogen, liquid oxygen ground support equipment and unique detail spares of liquid hydrogen and liquid oxygen transfer units	4.3
Dalmo Victor Company A Division of Textron Belmont, California	Main communications (deep space) antenna systems	2.1
Electro-Optical Systems, Inc. Micro Systems, Inc. (Subsidiary) Pasadena, California	Temperature and pressure transducer instrumentation	8.7
Garrett Corporation AiResearch Mfg. Division Los Angeles, California	Environmental control system	45.3

TABLE 4. Major Apollo Subcontractors (continued)
(contracts in excess of $1 million)

Company	System	Approx. Value as of April 1966 (in millions of dollars)
Leach Corporation Azusa, California	Apollo flight qualification recorder	$1.0
Ling-Temco-Vaught, Incorporated Dallas, Texas	Selective stagnation radiator system	1.2
Lockheed Propulsion Company Redlands, California	Launch escape and pitch control motors	7.9
The Marquardt Corporation Van Nuys, California	Reaction control motors for service module	29.8
Microdot, Incorporated Instrumentation Division South Pasadena, California	Stress measurement system	1.5
Motorola, Inc. Scottsdale, Arizona	Digital data up-link	9.5
Northrop Corporation Ventura Division Newbury Park, California	Earth landing system	36.6
Radiation Incorporated Melbourne, Florida	Automated telemetry data processing system (during vehicle testing)	3.5
RCA Electronics Princeton, New Jersey	Television cameras	3.8
General Motors Corporation Allison Division Indianapolis, Indiana	Fuel and oxidizer tanks	8.4
General Precision, Inc. Link Division Bingham, New York	Mission simulator trainer	36.6
General Time Corporation ACRONETICS Division Rolling Meadows, Illinois	Central timing system	4.5
Giannini Controls Durate, California	Reaction control gauging system	8.1
Gibbs Manufacturing and Research Corporation (Hammond Organ Co.) Janesville, Wisconsin	Mechanical timers and mechanical clocks	1.8

TABLE 4. Major Apollo Subcontractors (concluded)
(contracts in excess of $1 million)

Company	System	Approx. Value as of April 1966 (in millions of dollars)
B.H. Hadley Company Pomona, California	Pressure helium regulator unit and liquid hydrogen tank vent disconnects	$1.5
Honeywell Minneapolis, Minnesota	Stabilization and control	98.4
Kinetics Corporation Solana Beach, California	Power transfer and motor driven switches	1.8
Rosemount Engineering Company Minneapolis, Minnesota	Transducers and MASS flowmeter	1.1
Sciaky Bros., Incorporated Chicago, Illinois	Tooling, welding and machinery	1.7
Simmonds Precision Products Tarrytown, New York	Propellant gauging mixture ratio control	11.4
Thiokol Chemical Corporation Elkton Division, Elkton, Maryland	Escape system jettison motors	3.0
Transco Products, Inc. Venice, California	Telemetry antenna system (R&D)	1.0
United Aircraft Corporation Pratt & Whitney Aircraft East Hartford, Connecticut	Fuel cell	60.3
Western Instruments, Incorporated Newark, New Jersey	Electrical indicating meters	2.0
Westinghouse Electric Aerospace Electrical Division Lima, Ohio	Static inverter conversion unit	4.9

Source: Ralph B. Oakley, "Historical Summary, S&ID Apollo Program," North American Aviation, January 20, 1966.

Teague became particularly concerned that many small contractors were becoming victims of the intricacies of dealing with the government:

> It is obvious to me that many small business firms are not made aware of the subtleties involved in NASA contracts and tend to deal with NASA procurement and engineering personnel on a basis of personal trust, much as they do in commercial practices. However, many of them soon discover that they cannot rely on the verbal promises and assurances of NASA personnel and hence are heavily and unfairly penalized because they chose to trust the "word" rather than a written document.[27]

On the other hand, he observed, larger NASA contractors seemed to have little trouble in getting their contracts adjusted when financial or other problems developed.

Teague expressed bewilderment about the inconsistency of government which expressed full support for the preservation of small business firms, but permitted government procurement lawyers to protect government agents who made oral assurances to small businesses which resulted in their failure to receive reimbursement for "work honestly and faithfully performed."[28] Although he may for a time have provided some measure of relief for small businessmen by being a "go-between" for them with larger firms and NASA, the financial and contractual arrangements by NASA tended to become more complex and difficult, and less accessible to small businesses. Nevertheless, many small businesses became successful large businesses because of their NASA contracts, and made significant contributions to the space program.

Contracting related not only to engineering and design, but also to technical services and maintenance. MSC contracted out facilities and grounds maintenance, food services, on-site transportation shuttle systems, library services, and archival services. Procurement stressed purchases from existing stocks of private suppliers. Thus the economic impact on the community and the state tended to be very broad. While the romance and adventure of spaceflight certainly attracted admirers and attention, the very great economic impact of MSC on the Houston, Texas, and Gulf Coast communities generated strong self-interested, but no less real, public support for NASA programs.

Magazines such as *U.S. News and World Report* began to talk about a new space frontier in the "Southern Crescent." Texas, Louisiana, Mississippi, Alabama and Florida, stretching along the Gulf Coast, became the home of new NASA centers and installations and their hosts of private contractors and suppliers. Nationally, NASA contracts rose sevenfold between 1960 and 1965, from 44,000 to some 300,000 contracts being managed by NASA engineers and scientists, while the number of NASA employees rose to three times that of 1960 levels. It meant that relatively fewer NASA managers were managing more contracts, and that more of NASA's engineers were becoming contract administrators and project managers.[29]

Public interest in the Apollo-Saturn program heightened as real space hardware began to be shipped to MSC, Marshall Space Flight Center, and Kennedy Space Center. North American and its subcontractors first designed and built mockup or simulated modules and components for tests and evaluations. These were usually followed by the construction of boilerplate modules built on the design and weight specifications of the Apollo spacecraft, but not man-rated. The boilerplate modules were used for a variety of tests (such as water impact, parachute, flotation, launch compatibility) and for training. North American delivered its first boilerplate modules in September 1962, and by mid-1964 some 30 boilerplate modules were being used for various tests, including 5 launches on Little Joe II rockets. In February and again in May 1965, Apollo boilerplate modules were adapted to successfully launch Pegasus satellites into orbit. Finally, in October 1965, and basically on schedule, North American delivered the first actual Apollo spacecraft, SC-009, to Kennedy Space Center.[30]

North American's mobilization of resources for Apollo production peaked in 1965. In that year alone, North American's Space and Information Systems Division added more than 5000 employees, and division employment, almost wholly concentrated on Apollo production, peaked at 35,385 persons. Subcontractors similarly were in full production by 1965. Over 400,000 people were at work on NASA's space programs by mid-year. NASA expenditures from 1964 through 1967 approximated $5 billion each year and declined thereafter. The comparative level of NASA economic activity indicated by table 5 should be viewed in the context of a few broader economic parameters. During the same 4-year period (1964-1967), federal defense expenditures rose from $50 to $70 billion per year, the cost of government health programs with the introduction of medicare rose from $1.7 to $6.6 billion a year, and total federal expenditures increased by about one-third.[31]

Growing federal expenditures and inflation generated efforts at economy in all federal agencies, including NASA. One of the anomalies of the space program is that NASA's

TABLE 5. NASA Budget and Personnel Status

Fiscal Year	Appropriated	NASA	Contractors (estimated)	Total
1959	$330.9 million	--	--	--
1960	523.6 million	10,000	37,000	48,000
1961	966.7 million	17,000	58,000	75,000
1962	1,825.3 billion	22,000	116,000	138,000
1963	3,674.1 billion	28,000	218,000	246,000
1964	5,100.0 billion	32,000	347,000	379,000
1965	5,250.0 billion	33,000	377,000	410,000
1966	5,175.0 billion	34,000	360,000	394,000
1967	4,968.0 billion	34,000	273,000	307,000
1968	4,588.9 billion	33,000	235,000	268,000
1969	3,953.0 billion	32,000	186,000	218,000
1970	3,696.6 billion	31,000	135,000	166,000
1971	3,333.0 billion (request)	30,500	113,000	144,000

Source: FY 1971 Interim Operating Plan News Conference, Apollo Series, JSC History Office.

budget and the number of contractor-employed personnel began a downward slide well before the first Saturn-Apollo launch. At the time the Apollo program enjoyed its greatest successes (1969-1970), NASA operated with 25 percent less money than the peak 1965 budget, and total contractor personnel had declined by almost 50 percent. MSC's civil service employment peaked at 4731 (full-time equivalent employees) in 1967, and 2 years later support contractor personnel peaked at 14,276. Under the duress of tightening budgets, MSC began in 1965 and 1966 to convert more of its cost-plus-fixed-fee contracts to cost-plus-incentive-fee contracts as had been done initially with McDonnell Douglas for the Gemini program. The motivation was both economy and efficiency. Negotiations for the conversion of the North American Apollo contract were completed in December 1965 and approved by NASA in January 1966.[32]

Major Apollo contractors now included Aerojet-General Corporation which produced the service module engine. AVCO Space developed the command module heat shield. Bell Aerospace produced the lunar module ascent stage engine. BellComm provided systems engineering and support to Headquarters. Bendix produced the lunar surface experiments package and command module instrumentation systems. Boeing monitored the integration of Saturn-Apollo components. Collins Radio provided communications and data subsystems. Eagle-Picher Company produced batteries for Mercury, Gemini, and Apollo systems. Garrett Corporation specialized in environmental control systems which allowed the astronaut to survive in a hostile environment. General Electric reviewed all programs for reliability and quality assurance. The AC Electronics Division of General Motors manufactured the guidance and navigation system. Grumman (discussed more fully in a following chapter) was the prime contractor for the lunar module and used many subcontractors as did each of the other prime contractors.[33]

Minneapolis-Honeywell worked on stabilization and control systems for all of the spaceflight programs. IBM helped design and build the Mission Control Center (unit 6) and the Saturn V instrument control unit, and International Latex Corporation built space suits. Lockheed manufactured the launch escape and pitch control engines, and Marquardt Corporation produced the reaction control system for the lunar module and the service module. Motorola provided the digital command system; Northrop the landing system; RCA the television, guidance and communications equipment; Raytheon the command module computers; and Space Technology Laboratories (TRW) the lunar module descent stage engine.[34]

Finally, Thiokol built the launch escape tower motor and TRW Systems, Inc. provided trajectory analysis support. United Aircraft's Hamilton Standard Division developed the environmental system for the lunar module, and as previously mentioned, Pratt and Whitney designed and built the fuel cell power units. Philco-Ford, also reviewed in a following chapter, was the primary contractor in the design and development of the Mission Control Center. The most involved of these contractors, of course, was North American, which was the prime contractor for the Apollo.[35] Not only did American business profit financially from the space program, but American industry achieved significant technological growth by doing things that had never been done before.

Fuel cells, metal and ceramic manufacturing, computer design, environmental systems, and human health benefited greatly. Manufacturing processes experienced critical breakthroughs in specific technology such as wraparound tooling, cold bonding, and multilayer circuit board soldering; and even precision hole-drilling through steel, titanium, and composite honeycomb materials had broad applications throughout American industry.[36] Space was business, but more importantly it was a learning business.

Clearly, part of the product of that learning would be the development of new technology, that is, how to create and build new machines, how to operate those machines, and how to do things better or differently than had been done before. A great part of that learning experience, it was anticipated, would have to do with the physical properties of objects and materials found in space—and more specifically on the Moon. Preoccupied with building rockets and spacecraft, NASA engineers gave little thought to what those astronauts might find if and when they landed on the Moon, or the consequences such an event might have on the human learning experience.

In 1964, Elbert A. King, Jr., and Donald A. Flory, who joined the MSC Space Environment Division the previous year, submitted to Max Faget, the Director of Engineering and Development, plans for a laboratory to receive lunar materials where they would be repackaged for distribution to scientists for study. After several refinements, plans for the laboratory went to Headquarters for approval and funding. Headquarters responded "cautiously," David Compton explained in his history of the Apollo lunar exploration missions, and noted that such a laboratory and distribution of lunar samples would be the responsibility of Headquarters. Willis Foster, who headed the Manned Space Science Division at Headquarters, tentatively approved $100,000 for a laboratory design study rather than the $300,000 requested, and created an ad hoc committee of Headquarters personnel and MSC scientists to study the problem.[37] But the Lunar Receiving Laboratory almost got lost in the delays resulting from Headquarters' and MSC's attempts to resolve their differences over the proposed laboratory, in the disputes that began to arise between the science community and NASA, and in Congress' growing desperation to cut government expenditures.

While the NASA ad hoc group studied and "ruminated on the need for a receiving laboratory," at the instigation of Homer Newell, Associate Administrator of the Office of Space Sciences and Applications, a special advisory committee including three persons from the Space Science Board and two academic scientists representing the broader scientific community, met to discuss management and distribution of lunar materials. The committee advised that studies of lunar materials should be conducted by the scientific community at large, that a receiving laboratory need not be located at MSC (unless it could be properly staffed), and that strict quarantine procedures should be imposed to prevent possible biological "back-contamination" by extraterrestrial materials. Headquarters and MSC jousted for a time about who should manage the receiving laboratory, how it would be designed, and how much it would cost. Just about the time NASA concluded its deliberations, Congress decided that a Lunar Receiving Laboratory would not be needed and struck funding for it from the authorization bill.[38]

Rehearings resulted in the restoration of the $9.1 million request for the laboratory, but Congress meanwhile reduced NASA's overall budget for facilities construction by $18.2 million and its administrative budget by $23.9 million. These cuts, Compton suggests, did affect the construction and operation of the Lunar Receiving Laboratory. Nevertheless, with designs developed by the Oak Ridge National Laboratory of the Atomic Energy Commission and Headquarters' approval of the contract award by MSC, construction began on the

$7.8 million Lunar Receiving Laboratory in July and August 1966 with contracts let to Warrior Constructors, Inc. of Houston for preliminary work, and to National Electronics Corporation of Houston and Notkin and Company of Kansas City, Missouri, for completion.[39]

As did design and construction, staffing became mired in seemingly interminable committee studies, in an apparent disinterest by scientists to work in Houston, cost problems, interagency discussions (as between NASA and the Public Health Service), and general bureaucratic procedures and irresolution. Finally, in 1967, MSC Director Bob Gilruth created a Science and Applications Directorate with authority over the Lunar Receiving Laboratory being completed. While a search for a decision on staffing the laboratory and for a permanent laboratory manager slowly unwound, Gilruth appointed Joseph V. Piland, who managed the laboratory construction, as the laboratory's acting manager.[40] The problems developing with the Lunar Receiving Laboratory illustrate the growing complexity of the space business and of doing business with the government. Decisions became increasingly difficult as broader elements of society were affected by those decisions.

Government contracts and firms doing business with the government required more and more supervision, not only by NASA managers, but by a growing host of "outside" government agencies. Beginning in the 1960's the creation of new regulatory agencies and bodies accelerated, with 20 new agencies being added in the decade of the seventies alone. The Environmental Protection Agency created by the National Environmental Policy Act (1969), the Occupational Safety and Health Act of 1970 which established the Occupational Safety and Health Administration (OSHA), plus affirmative action, small business, disadvantaged business laws, and changes in worker compensation, tax codes, and reporting procedures were but a few of the growing administrative burdens encountered by government contractors and, to be sure, by firms doing business anywhere. These regulations, as will be seen in a later chapter, created problems but also opportunities.

Given the inherent difficulties of building a machine that was being designed as it was being built, plus the growing complexities of the business environment, not to mention the weakening economy and signs of weakening congressional and public support for space expenditures, and a real decline (after 1966) in the number of NASA contracts and the rising costs of doing business (including higher interest rates and inflation), aerospace firms (despite their apparent successes) were growing more and more financially exposed and vulnerable. Just as Apollo began to fly and great achievements and expectations in space emerged, the technical infrastructure for space ventures outside of NASA, that is, the private contracting community upon which the entire space program ultimately depended and which received roughly 80 percent of NASA expenditures—as well as NASA itself—faced declining budgets, employment reductions, and rising complexities and costs in the manner of their doing business.

In 1967 these problems seemed somehow remote. There was pressing business at hand. NASA engineers and North American and its subcontractors concentrated on the corrective actions, design improvements, modifications, and production of the Saturn-Apollo spacecraft. Grumman pushed development of the LEM. Construction finally began on the Lunar Receiving Laboratory. The first launch of a flight-ready spacecraft (017) aboard the Saturn V occurred, in November 1967 (Apollo 4). NASA flight-tested a lunar module (LM-1) aboard a Saturn IB in January 1968 (Apollo 5), and in April the launch of a Saturn V stack (Apollo 6) proved that the mission support systems could respond to emergencies caused by serious malfunctions in the propulsion systems. The spacecraft and its components lurched into totally unplanned orbits (Apollo 6), but flight directors were able to save and control the flight.[41] NASA decided it was time to return to flight.

On October 11, 1968, astronauts Walter Schirra, Donn Eisele, and Walt Cunningham awaited lift-off in the redesigned Apollo 7 spacecraft secured to the Saturn IB booster. Eleven years earlier, the Soviet Sputnik began orbiting Earth and created that massive response that brought NASA into being and the astronauts to their place at this appointed hour. Only 15 months before, with the destruction of AS-204, the entire Apollo program was forced into a reevaluation and redesign. The future then seemed dark. Now, a lunar landing within the decade finally seemed truly possible.

Apollo 7 made a smooth lift-off and returned on October 22, following an 11-day mission which proved the space-worthiness of the vehicle and the astronauts. The flight also featured the first live television broadcasts from a manned spacecraft. If it had ever lagged, the public's interest in spaceflight rekindled.[42] Interestingly, within a few years of that launch, each of the three astronauts aboard Apollo 7 became business managers in the private sector, perhaps lending credence to the close interrelationship between the public and private sectors of the space-related economy.

Cunningham, a Marine aviator with an undergraduate and graduate degree in physics, resigned from NASA in 1971 to organize and become president of a Houston-based company called HydroTech Development. In 1976 he became a senior vice-president and Director of Engineering for 3D International in Houston. Donn Eisele, the command pilot for Apollo 7, left the astronaut corps in 1970 and became the Technical Assistant for Manned Flight at the Langley Research Center before retiring from NASA in 1972 to become the Peace Corps Director in Thailand. Later he joined the Oppenheimer investment firm in Ft. Lauderdale, Florida. Walter (Wally) Schirra, known in the astronaut corps for his good humor and practical jokes (once, when asked for a specimen, he delivered to the nurse a 5-gallon jug of water discolored with iodine), flew Mercury, Gemini, and the Apollo 7 flight. He retired from NASA and the Navy in 1967 and became Chairman and Chief Executive Officer of Environmental Control Company in Colorado, before becoming Director of Marketing-Powerplant and Aerospace Systems for Johns Manville Corporation.[43]

In a sense, the flight of Apollo 7 marked the apogee, that is, the high point, of the Apollo program insofar as the contractors were concerned. By now all Apollo systems were in full production. The design and manufacturing problems had been seemingly resolved. Employment levels among NASA contractors were declining, as were the dollars being spent on Apollo and other space-related contracts. How had NASA and its contractors gotten from the point where manned spaceflight had been at best an idle dream to the moment when man's first step on the Moon seemed both imminent and practical? What would come after Apollo? And what would flights to the Moon mean to people on Earth?

Dr. Edward C. Welsh, Executive Secretary of the Space Council, addressed these questions in a talk to the Science Industry Committee of the Metropolitan Washington Board of Trade. Putting federal money into space, he assured everyone, is not taking dollars away from anybody—"every bit of that money [spent on space] is spent right here on Earth, rather than out on the Moon or some other heavenly body." And this financial investment, he stressed, "is bringing in substantial returns to people in every state of the union." Space activity, he said, "is both productive and creative. It puts to work—producing, creating, and doing—some of our most valuable resources such as skilled manpower and modern facilities." NASA's contractual relationships "brings together into a constructive team all of the major elements in our country devoted to technical progress" and technological leadership.[44]

The space program,Welsh believed, developed methods, techniques and procedures which increased the efficiency and profit of a broad spectrum of American enterprise, within and without the aerospace industries. Economic benefits included worldwide communications systems, global weather data and forecasting, and navigational aids. Manufacturers learned new things about heat, metallurgy, alloys, plastics, and ceramics. Computer and electronic technology experienced a veritable revolution, in good measure because of inputs and incentives from the space program.[45] Education, he said, benefited from the space program, not only by direct assistance in the form of scholarships and fellowships and laboratories and research grants funded by NASA, but in the broader dimensions of new knowledge about the heavens and the Earth and of humankind. Medical instrumentation improved markedly as a result of electronic applications from the space program and was beginning "to revolutionize the equipment of clinics, hospitals, and doctor's offices." Concurrently, national security and international relations were greatly enhanced by America's space program. It helped depict and disseminate the Nation's vitality and strength "in ideas, in technology, in freedom, in standards of living, in education, and in objectives for peace."[46] All this while the Moon and a lunar landing still seemed so distant? Welsh's rhetoric and NASA reassurances seemed to fall on a growing number of deaf ears, as Americans at the close of the decade began to weigh the costs of the War on Poverty, the war in southeast Asia, the cold war and rising federal deficits and inflation.

America's mobilization for space peaked in 1965. It had thus far been a unique experience. The mobilization had been peaceful, and with peaceful intent, and was accomplished through conventional free-market mechanisms and notably by contracts. Through the mechanism of the primary contract and subcontracts, with oversight by NASA technical managers, space business became an integrated collectivist enterprise. Almost one-half million Americans, about 35,000 NASA employees and 410,000 contractor employees, were at one time directly involved in the space program. The numbers involved and the dollars committed to space began to decline long before the Apollo program peaked. By 1969 Apollo was a product of a full decade of effort by a broad spectrum of American society. By 1969 the Nation had committed $37 billion of its resources and a considerable portion of its technical expertise and personnel to NASA. Because of NASA and the national space programs the world was changing, but the nature and extent and necessity of those changes was still not at all clear to most Americans.

Soon they, and the other people on Earth, began to see themselves from a different perspective. American astronauts aboard Apollo 8 circled the Moon. Those from Apollo 11 orbited the Moon, landed on the Moon, walked upon its surface and returned safely to Earth.

They gazed upon Earth from another body in the solar system. Through their eyes, the people of the world saw Earth and themselves as they had never been seen before. No one, nor life on Earth, would be quite the same again.