



CHAPTER 9: *The Flight of Apollo*

The design and engineering of machines capable of taking humans into space evolved over time, and so too did the philosophy and procedures for operating those machines in a space environment. MSC personnel not only managed the design and construction of spacecraft, but the operation of those craft as well. Through the Mission Control Center, a mission control team with electronic tentacles linked the Apollo spacecraft and its three astronauts with components throughout the MSC, NASA, and the world. Through the flights of Apollo, MSC became a much more visible component of the NASA organization, and operations seemingly became a dominant focus of its energies. Successful flight operations required having instant access to all of the engineering expertise that went into the design and fabrication of the spacecraft and the ability to draw upon a host of supporting groups and activities.

N. Wayne Hale, Jr., who became a flight director for the later Space Transportation System (STS), or Space Shuttle, missions, compared the flights of Apollo and the Shuttle as equivalent to operating a very large and very complex battleship. Apollo had a flight crew of only three while the Shuttle had seven. Instead of the thousands on board being physically involved in operating the battleship, the thousands who helped the astronauts fly Apollo were on the ground and tied to the command and lunar modules by the very sophisticated and advanced electronic and computer apparatus housed in Mission Control.¹ The flights of Apollo for the first time in history brought humans from Earth to walk upon another celestial body.

Apollo is perceived in modern times as the ancients' sun-god, a god of light and of the heavens whose chariot raced across the night skies like a shooting star. Greek mythology ascribes to Apollo much earlier and more simple roles. He appears in Greek writings variously as the god of agriculture, the protector of cattle and herds, the deity of youth and manhood, a warlike god, and a god of prophecy, of healing, and of music (so long as that music came from the lyre). At the height of Greek civilization, as Athens particularly began to colonize throughout Ionia and the Mediterranean world, Apollo became a maritime deity, the "dolphin" god who accompanied emigrants on their voyages. Thus in modern times, fittingly perhaps, another Apollo carried the first voyagers from Earth to a distant heavenly body. "Houston, Tranquility Base here, the Eagle has landed," astronaut Neil Armstrong radioed from the lunar surface to the Mission Control Center as the Apollo 11 mission touched down on July 20, 1969.² The journey from here to there had been fraught with peril, difficulties, and bold decisions, and had been made possible by tens of thousands of people who never left Earth.

Other than the astronauts, those most directly involved in the Apollo flights were the personnel at MSC who held and managed those fragile, invisible, extended lifelines to the command service module (CSM) and the lunar excursion module (LEM). (The LEM later became known simply as the lunar module (LM) after NASA's associate administrator for Manned Space Flight, George Mueller, protested that "excursion" in the title sounded a bit

frivolous.) In coordination with Goddard Space Flight Center, Mission Control linked the spacecraft to its launch and recovery crews; to a worldwide tracking and communications network; to elements of the technical and scientific personnel at every NASA center; to engineers and specialists at Kennedy Space Center, Marshall Space Flight Center, MSC, and other NASA centers as needed; and to a host of contractor engineers scattered around the United States and the world. The Department of Defense (DoD) supported flight operations in staffing and maintaining the tracking and communications network, in the operation of recovery fleets, and in the deployment of medical and rescue forces. The National Weather Service and the National Oceanic and Atmospheric Administration constantly monitored weather and ocean conditions for launch, flight and recovery operations. The National Laboratories, particularly the Los Alamos Laboratory, provided support for the development and operation of lunar surface experiments. For every astronaut in space, there were many thousands of persons on duty on Earth.

The Apollo program included 11 piloted missions: 9 went to the vicinity of the Moon, and 6 of those landed men on the Moon. The first manned Apollo flight, an Earth-orbital mission lofted by the Saturn IB, flew on October 11, 1968, only 5 days after NASA Administrator James Webb retired and relinquished his duties to Thomas Paine, who became the Acting Administrator. In December 1968, astronauts orbited the Moon; in March 1969, rendezvous and docking procedures were checked in an Earth orbit; in May, Apollo 10 tested equipment and procedures in a lunar orbit and in July, NASA achieved John Kennedy's goal of landing men on the Moon and returning them safely to Earth. There followed in November another, more extended, sojourn on the lunar surface. Then Apollo 13, the only Apollo flight of 1970, failed in its mission but succeeded in returning its passengers safely to Earth.³ Not only had the design and engineering of machines capable of taking humans into space evolved over time, but so too did the philosophy and procedures for operating those machines in a space environment.

In 1961, when manned lunar flights were being seriously debated, Max Faget recalled that "the basic understanding of the venture was quite primitive." A ship returning from a lunar voyage faced a much more difficult injection into the Earth's atmosphere than did one in Earth orbit. It would be traveling much faster. It had to hit the Earth's atmosphere at the right angle. Too shallow an angle and the vehicle might "skip" off the Earth's atmosphere; too steep an approach would result in certain incineration. Moreover, the human body's adaptation to space might be different from adaptation to Earth orbit. Communications and control over vastly greater distances than Earth orbit were untested. The unknown weighed far more heavily than the known.⁴ That, of course, is precisely what made the enterprise so challenging and exciting.

Faget pointed out that the decision to land a vehicle on the Moon from lunar orbit had a major impact on the design and construction of Apollo. Lunar rendezvous meant that Apollo would require two spacecraft: a command and service module for the flight to lunar orbit and back and a separate lunar module for descent to the surface of the Moon and return to lunar orbit rendezvous with the command ship. Moreover the lunar orbit decision markedly affected operational techniques.⁵

Eugene F. Kranz, who served as Chief of the Flight Control Division at MSC throughout the Apollo flights, reconstructed the progression in flight operations from

NASA and DoD — Partners in Recovery

by Jerome B. Hammack, Chief,
Landing and Recovery Division for the Apollo Missions

Early on, NASA decided to have water landings for space capsules (capsules in the early days, then spacecraft as we became more sophisticated) both because water would provide a softer landing and Earth is more water than land. But who was going to recover the capsule? The Navy had most of the ships and the Air Force, and indeed the Army, to assist in this vital part of the mission.

It did not take much persuasion by NASA to get the DoD to become a partner in this vital area of space missions. As things evolved, the DoD set up a single point of contact (the commander of Patrick Air Force Base) through which NASA would levy recovery requirements for each mission. For recovery activities, I was his NASA counterpart. My division—the Landing and Recovery Division (LRD)—was composed of about 100 people, most of whom were engineers. We developed flotation collars and locator beacons, coordinated various recovery hardware on the development of the capsule, and—most important—worked out the mission operations recovery phase of the mission. That phase included training the astronauts in a tank and in open water. The open water part of the training was the most fun. LRD procured its own vessel (an LSD) from the Army, modified it with a handsome bridge, and “sailed” out into the Gulf of Mexico. After putting the astronauts in a capsule in open water, the flotation collar would be deployed, and the helicopters would fly in to recover the astronauts from the side of the capsule and hoist them up into the helicopter. Then a specially designed davit crane would lift the capsule from the water onto the deck of the ship. After several such exercises, the good ship “Retriever,” as it was called, would return to port trailing many fishing lines.

The DoD requisitioned ships and aircraft from line units and assembled a recovery task force. In the early days, a typical recovery task force consisted of four ships and several dozen aircraft: helicopter and fixed-wing. The primary recovery ship (usually an aircraft carrier) would be stationed at the primary landing point and three secondary landing points were covered by other type ships (such as destroyers, minesweepers, escort ships). The aircraft would be uprange and downrange of the primary landing point and at contingency landing points throughout the world. The ship requirements were passed to two Navy commanders—one in the Atlantic and one in the Pacific—who each led a Commander Task Force (CTF). The Atlantic unit was CTF-140 and the Pacific unit was CTF-130. The commanders were usually two-star admirals with collateral duties. (For example, the CTF-130 commander was also the commander of Pearl Harbor Naval Station.) Each commander had a staff of officers to plan the support details. Aircraft search requirements were passed to the Air Force Rescue Command where search and rescue aircraft such as the C-130 were assigned.

The ships would embark prior to lift-off in order to be at their assigned stations at the beginning of the mission. Each ship carried its company of officers and crew as well as the LRD recovery engineers and coordinators. The LRD group was responsible for training the ship's crew and briefing them on mission details and characteristics of the capsule—especially any hazards such as the hypergolics and other toxic fluids. We were a good team filled with life and good humor (I was often the object of the Navy pilots' high-spirited schemes) and with the importance of the work we were doing.

One of the big concerns surrounding early Apollo lunar flight recoveries was the fear of contaminating the Earth. Some scientists feared the astronaut crew would bring back pathogens from the lunar surface and pushed for an isolation system. Although the chance for something like that was remote, given the hostile and sterile environment of the Moon, no one came forward to say it could not be. So the plan was to pick up the crew in the capsule, transport it to the carrier deck with the crew inside, and then have them walk through a tunnel into a mobile quarantine facility (MQF). (The MQF was a highly modified Airstream trailer that supposedly would contain any lunar pathogens.) The crew would remain in the MQF until the carrier docked and the capsule was transported (by Air Force cargo airplane) to Houston and placed alongside an elaborate lunar receiving laboratory. The astronauts would continue to live in the MQF for several days to make sure they did not develop any diseases and that no lunar pathogens were present.

However, sometime before the first Apollo lunar flight, the scientists asked that the capsule air vents be closed after landing. We (LRD) objected to sealing up the crew in the moist, hot conditions of the south Pacific. In fact, LRD personnel were already concerned about lifting the capsule with the crew inside—concerned about a possible crane malfunction. For the safety of the crew, we proposed that they emerge from the capsule in the usual manner after splashdown, be scrubbed down with various disinfectant solutions, and put in a quarantine area in the helicopter. After landing on the carrier, the crew would then walk through the tunnel to the MQF. This method was finally approved. After several missions, it became apparent that lunar pathogens were not a problem, and the MQF procedure was removed from the recovery plan.

Ironically, toward the end of the Apollo program—toward the end of water landings—shipboard cranes were so improved that the last recovery operations used the crane to lift the capsule with the astronauts inside. Landing points had also become more precise. Recovery ships were generally in such close proximity to splashdown that little ship maneuvering was necessary.

Mercury to Apollo. He described Mercury operations (where he served as head of the Flight Operations Section in the Flight Control Operations Branch under John Hodge) as a “part-time” business. “The thought processes [for Mercury] were closely attuned to conventional aircraft, that is they were five-mile-a-minute thought processes.” Operations people spent

perhaps 3 weeks planning a Mercury mission. Mission rules and pilot operating procedures were contained in a 10- to 12-page pilot's handbook similar to that used for a military aircraft mission. The approach to Mercury was simplistic. Spaceflight operations were novel, and operators were novices. First Mercury and then Gemini flight experiences provided critical training for Apollo flights. Operating teams learned particularly that space was a vastly different environment, that part-time operations would not work, and that flight planning, training, preparation, and new organizational structures and greatly broadened support bases must be developed.⁶

John Hodge, Assistant Chief for Flight Control, agreed that the entire concept of flight operations was being constructed out of "whole cloth." But the conceptual design of the Mission Control Center and the basic principles of Apollo operations were completed even before Alan Shepard made the first suborbital flight on a Redstone rocket in May 1961.⁷ Flight operations required a great deal of foresight and a lot of learning by doing.

Kranz's association with flight began at a relatively early age and covered the full spectrum of NASA history from Mercury through the Shuttle. During World War II, his mother ran a boardinghouse located close to a USO (United Services Organization) which attracted a continual stream of transient military types. One of these, he remembered, was Billy Huffman, a combat photographer who flew numerous Ruhr bombing missions; and another was Rinehart Brandt who flew in the Battle of the Coral Sea among other engagements. Kranz developed a keen interest in flying and spent his free time around Franklin Field, Ohio. In high school he wrote his thesis on interplanetary flight and then attended Parks College of St. Louis University where he received a degree in aeronautical engineering. After a time as a test pilot with McDonnell Aircraft, he entered the Air Force near the close of the Korean War, spending time at Lackland, Spence, Laughlin, and Williams Air Force Bases, before a 15-month Asian tour with the 13th Air Task Force "showing the flag." When General Curtis LeMay decided that the Air Force did not need anymore fighter pilots and scheduled Kranz for "tanker" school, he opted to return to the more challenging and exciting life as a McDonnell flight test engineer.⁸

Kranz, in Formosa when the Soviets launched Sputnik, was indelibly impressed. The Soviets had it and the United States did not! When the Space Task Group was formed, Chris C. Critzos, who became Christopher C. Kraft's executive assistant in the Flight Operations Division, encouraged Kranz to join them. Gene Kranz said that his wife also encouraged him, thinking that their family life would become more stable and that he could also enroll in school in Virginia for graduate study.⁹ So the Kranz family went to Virginia, and in short order moved to Houston.

He became personally involved in every Mercury, Gemini, and Apollo flight. As programs shifted from Mercury to Gemini to Apollo, operations management became complex and deeply layered. "We applied the 'new knowledge' obtained from Mercury on Gemini," he said. The longer duration Gemini flights required far more intensive and sophisticated flight planning and preparation. Operations were now geared to a real-time, one-on-one interface with the astronauts. Flight control teams stood mission "watches." Flight directors began to develop flight "gouge" sheets, which established responses for given conditions and situations. Ed Nieman compiled the information into a formal systems handbook for flight operations. Finally, about the time of Gemini flights 6 and 7, flight

controllers began to address the problem of malfunction procedures (that is, the development of conditioned responses to difficulties). The very critical problem-solving function during flight operations began to become systematized.¹⁰ Spaceflight operations largely involved real-time (instant) problem solving.

For example, during the flight of Gemini 8, the vehicle began a rolling motion shortly after a redocking maneuver and as it passed out of contact with the ground stations. Assuming that the Agena rocket rather than the Gemini spacecraft was at fault, flight controllers ordered a shutdown of the attitude control systems which only accelerated the motion. Then, when ground control decided to separate the two vehicles, “everything went to hell in a handbag.” The point was we had made a “100 percent wrong call.” That taught us, among other things, that problems with the system needed to be fully resolved before flight, that all malfunction procedures needed to be carefully reviewed, and that the flight operations teams and astronauts required intensive training in malfunction procedures. In the Gemini 8 case, close attention to mission rules, reliance on thought processes and reactions ingrained by practice and simulation, plus (John Hodge thought) some heroic piloting by Neil Armstrong resulted in stabilizing the vehicle and a safe return. Overall, although flight remained a continual learning process, Gemini experiences generated confidence in the equipment and in operations procedures.¹¹

Max Faget agreed that Gemini was indispensable in developing the flight control techniques and procedures necessary for Apollo orbital rendezvous. Mercury and Gemini flight experiences defined the general philosophy of the interplay between the Mission Control Center in Houston and the astronauts in the spacecraft, and established the flight interrelationship between the NASA operating teams, hardware contractors, and contractor flight controllers.¹² By the time Apollo 8 rolled out on the launch pad, flight operations, while always a learning process, had sharpened and improved in comparison to early Mercury and Gemini operations.

Although the flight operations organization retained its general characteristics typical of Mercury days, that is with a Flight Control Operations Branch, an Operational Facilities Branch, and a Mission Control Center Branch reporting to the Chief (or Director) of the Flight Operations Division, the depth of the organization expanded rapidly during Gemini flights and in anticipation of Apollo, and the function of the branches or sections became more definitive. A brief comparison of the organization charts characteristic respectively of Mercury, Gemini, and Apollo flight operations (figures 9 to 11) depicts better than a lengthy narrative description the changing complexion of the operating systems. The organizational changes were actually much more fluid than the static tables indicate and, as characteristic of MSC, there were many relationships and semiformal structures that simply defy charting.

Notably, throughout most of the operational phases of Mercury, Gemini, and Apollo, irrespective of what the organizational charts suggested, the same lead persons were doing much the same job they did from the beginning. Chris Kraft, who began as assistant to Charles W. Mathews (whom Dennis Fielder described as the “grandfather” of flight operations) in the Flight Operations Division, became chief of the division in 1962, and John Hodge moved to the position of assistant chief. Under a reorganization in 1964, Kraft became Assistant Director of MSC for Flight Operations and Hodge became Chief of the Flight Control Division. When Hodge moved to Assistant Chief of Flight Control and then

to head the Flight Control Division, Gene Kranz, who had been Hodge's assistant in the Flight Operations Branch, replaced him. Concurrently, Dennis Fielder headed the Operational Facilities Branch, and Tecwyn Roberts was head of the Mission Control Center Branch. Interestingly, but for Kraft and Kranz, flight operations leadership relied heavily on the Canadian AVRO contingent (Fielder, Roberts and Hodge). During much of this time, of course, the Gemini Program Office was headed by James A. Chamberlin who led the movement of the AVRO engineers from Canada to NASA.

Although the list of "pioneers" in flight operations is too lengthy to fully develop and can be gleaned in part from the various Flight Control Division organizational tables, there was a remarkable continuity in the ranks. Jerry Brewer, for example, described by Fielder as a "dynamic personality" and very management-oriented, helped design long-term ground support systems. Robert F. Thompson, who headed the Shuttle Program Office, contributed significantly to the design of the recovery system. Bill Boyer and Howard Kyle helped develop the worldwide and real-time communications systems. Howard W. Tindall coordinated data from all divisions for the Apollo program. Much of that data came to him from the Mission Planning and Analysis Division where John Mayer, whom Chris Kraft referred to as "Mr. Mission Analysis," presided. Glynn Lunney, Clifford E. Charlesworth, John S. Llewellyn (all in flight dynamics), and Jerry Hammack, who moved from the Gemini Project Office where he served as Deputy Manager of Vehicles and Missions to head the Landing and Recovery Division for the Apollo flights, were among those who "cut their teeth" on Mercury and Gemini before tackling Apollo. By the time Apollo was ready to fly, MSC had become an operations-oriented organization with three directorates (Medical Research and Operations, Flight Crew Operations, and Flight Operations) supporting the Apollo flights (figure 12).

The state of readiness for Apollo operations rested heavily on Mercury and Gemini experiences. Those experiences, however, could not fully prepare anyone for Apollo flight. Apollo would go beyond the Moon and out of sight and sound of any point on Earth. It carried with it a two-stage space vehicle designed to land on the Moon, separate, and return to a rendezvous with the Apollo command module. Those who flew in the LM, unlike those who flew in Mercury, Gemini, or the Apollo command module, could not return directly to Earth in their craft.

Unmanned Apollo test flights resumed in November 1967, about one year following the AS-204 fire, and continued through 1968 when finally, in October, astronauts Walter M. Schirra, Jr., Donn F. Eisele, and R. Walter Cunningham flew the Apollo 7 command module on an Earth-orbital mission following a launch on a Saturn IB rocket.¹³

As 1968 neared its close, there had as yet been no manned flight tests of either the Saturn V rocket scheduled to launch Apollo to the Moon or of the capsule that would bring astronauts from the command module orbiting the Moon to the lunar surface. This was the year when Robert F. Kennedy and Martin Luther King both fell to assassin's bullets and when race riots erupted in every major city. President Lyndon B. Johnson said he would not seek reelection. Production of the LM was seriously behind schedule and NASA faced declining budgets. Remarkably, the major news event of the year had to do with a space voyage of exploration.¹⁴

Apollo flight plans called for carefully staged flight increments which would first test the Saturn V in Earth orbit; and in a following flight, test the LM in Earth orbit. Similar test flights would be flown in lunar orbit before a lunar landing was attempted. Nevertheless,

Flight Operations Division, 1962

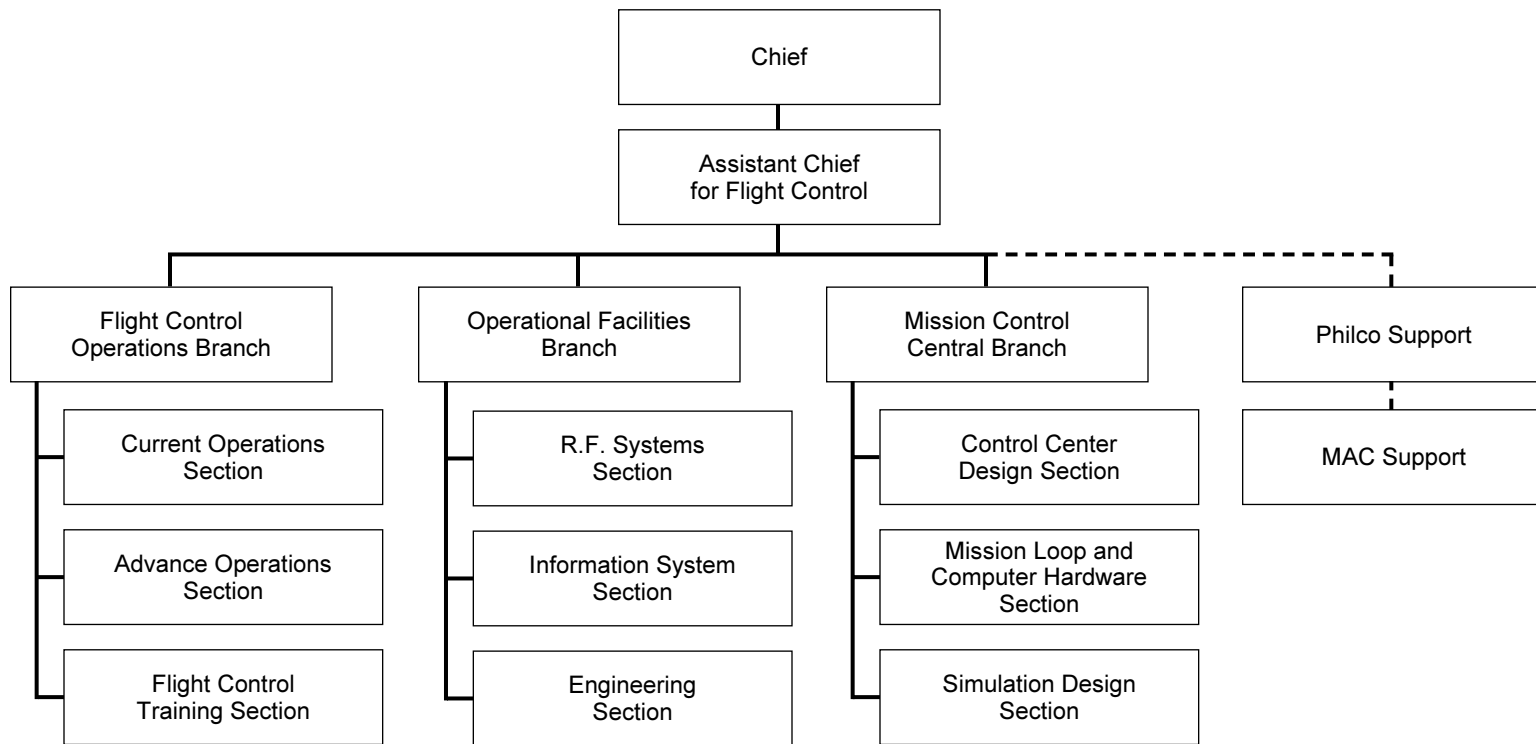


FIGURE 9. Flight Operations Division Organization as of December 1962

Flight Operations Directorate, 1964

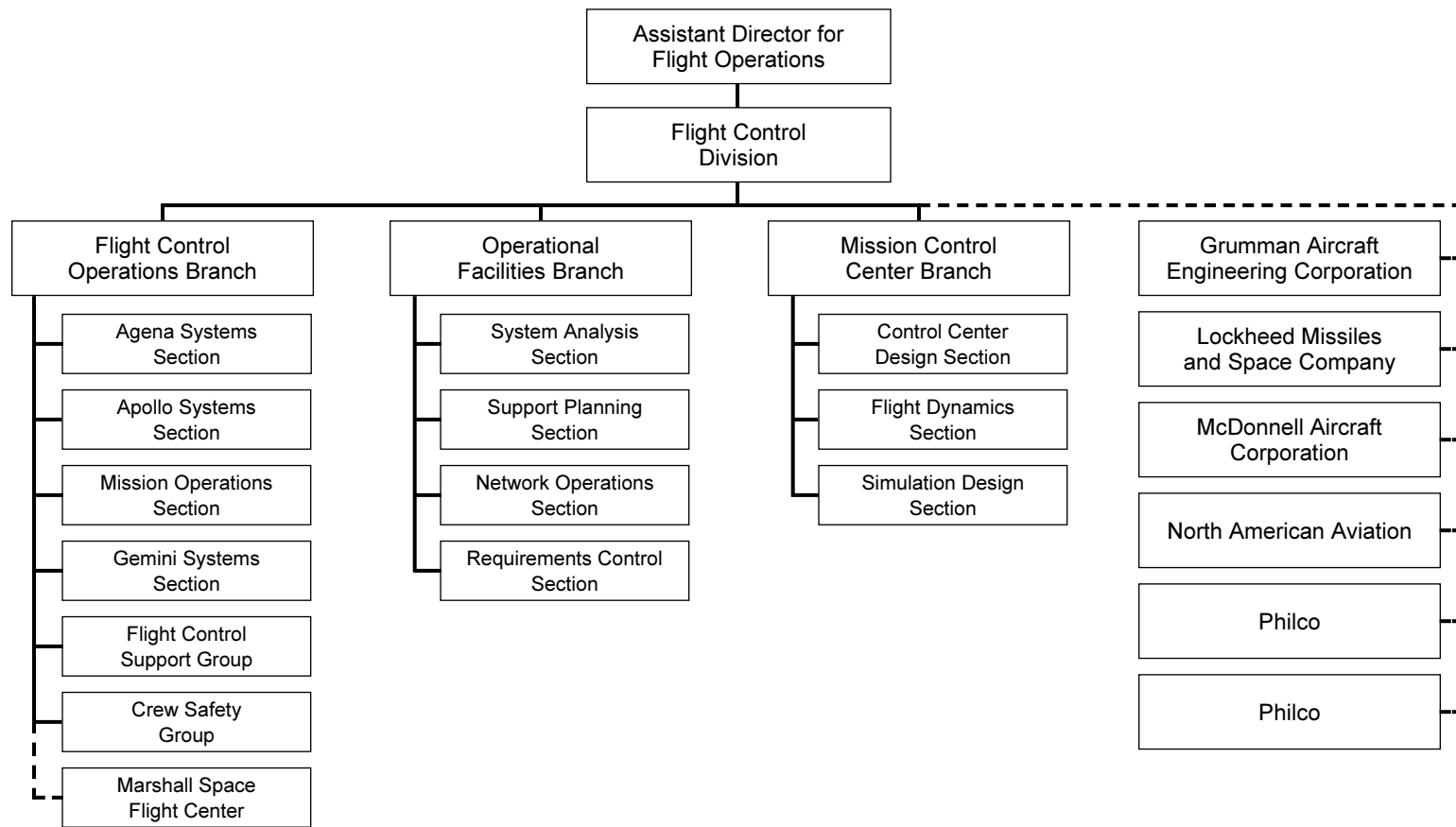


FIGURE 10. Flight Operations Directorate Organization as of January 1964

Flight Control Division, 1970

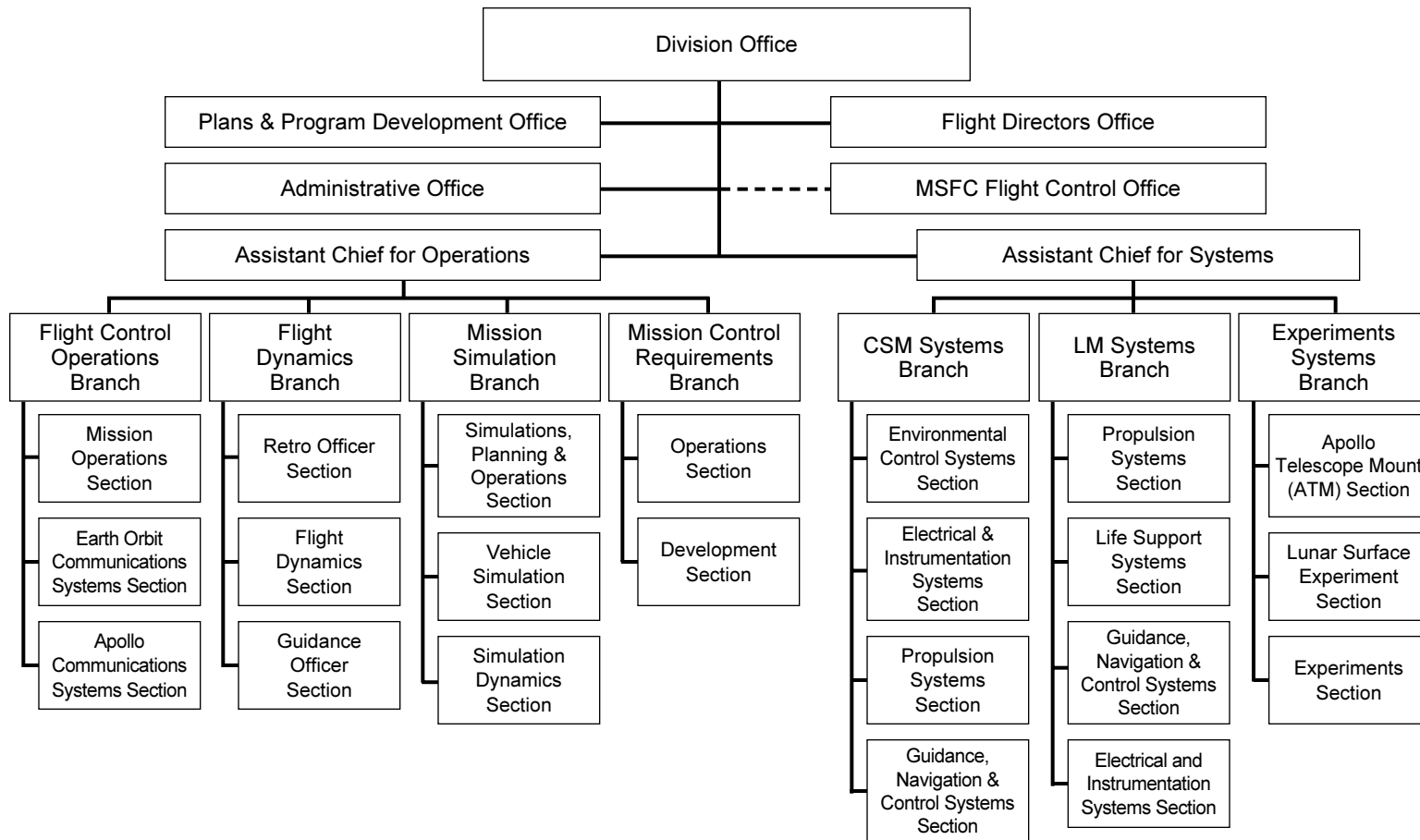


FIGURE 11. Flight Control Division Organization as of March 1970

George Low, manager of the Apollo Program at MSC, set the events in motion which resulted in leap-frogging or consolidating manned Apollo test flights into one bold lunar orbital mission. Low and Bob Gilruth first considered the possibilities in July, and then broadened their discussion to include Chris Kraft and Deke Slayton. On August 7, 1968, Low asked Chris Kraft, Director of Flight Operations, to develop a flight plan for an Apollo lunar mission. Frank Borman, who would fly in Apollo 8 to the Moon, recalled that he, Bill Tindall and Chris Kraft worked out a feasible flight plan in one afternoon.¹⁵

Low, with Carroll Bolender, Scott Simpkinson, and Owen Morris, then flew to Kennedy Space Center on August 8 to discuss a manned lunar flight with Apollo Program Director Sam Phillips, Kennedy Director Kurt Debus, and others. MSC Director Robert Gilruth endorsed the idea on August 9. That same day he, Low, Kraft, and Deke Slayton flew to Huntsville to meet with Kurt Debus and Rocco A. Petrone from Kennedy Space Center, Sam Phillips and George Hage from Headquarters, and Wernher von Braun, Eberhard Rees, Ludie G. Richard, and Lee James of the Marshall Space Flight Center. That group, representing NASA's manned spaceflight "field" centers, endorsed advancing the schedule for a manned lunar orbital flight. Next, on August 14, a representative group from the manned flight centers and their contractor representatives met with Deputy Administrator Thomas O. Paine. That body, with Paine, ratified the proposal to convert the Apollo 8 mission to a lunar flight.¹⁶

Apollo 8 was scheduled to be the first manned Apollo launch by a Saturn V, and it was originally scheduled to test the manned lunar module in an Earth orbit. The idea for changing it to a lunar flight originated with Low, was developed and refined cooperatively by managers from Kennedy Space Center, Marshall Space Flight Center, and MSC, and then presented to Headquarters for approval. During the initial discussions, Administrator Webb and George Mueller were both in Vienna. When informed by telephone on August 14, Mueller was distinctly cool to the idea, and Webb was "shocked by the audacity of the proposal" and inclined to say no; but after Paine cabled a detailed explanation, Webb instructed him to proceed with lunar flight plans but not to publicly divulge the plans.¹⁷ The inception of the Apollo 8 lunar flight plan provided an interesting example of Headquarters-center relations and of the essentially cooperative or collegial style of NASA management.

Meanwhile, Apollo 7 (which, incidentally, carried NASA's first manned in-flight television camera providing live coverage to the ground) made an eminently successful flight. MSC and other NASA units continued to study the lunar flight idea. George Mueller met with the Apollo Executives in early November and received their strong endorsement for a manned lunar orbital flight. Thomas Paine, now Acting Administrator following James Webb's retirement, listened to presentations from Sam Phillips, Lee B. James (the Saturn V manager at Huntsville), George Low, Chris Kraft and Rocco Petrone. He then received Gerald Truszynski's affirmation that the tracking network would be ready, and obtained mission support from DoD before approving the Apollo 8 lunar flight for December 21, 1968.¹⁸

That decision began NASA's "assault on the Moon." Cliff Charlesworth, Flight Director for Apollo 8, recalled that "Apollo 8 was the highlight of the Apollo program. The commitment to do the flight took a lot of courage." A manned lunar-ready (Block II) command module had only flown once (Apollo 7). A Saturn V had never been used to boost a manned vehicle into space. The "deep space" voice communication system had obviously

Manned Spacecraft Center, 1968

Suddenly, Tomorrow Came . . .

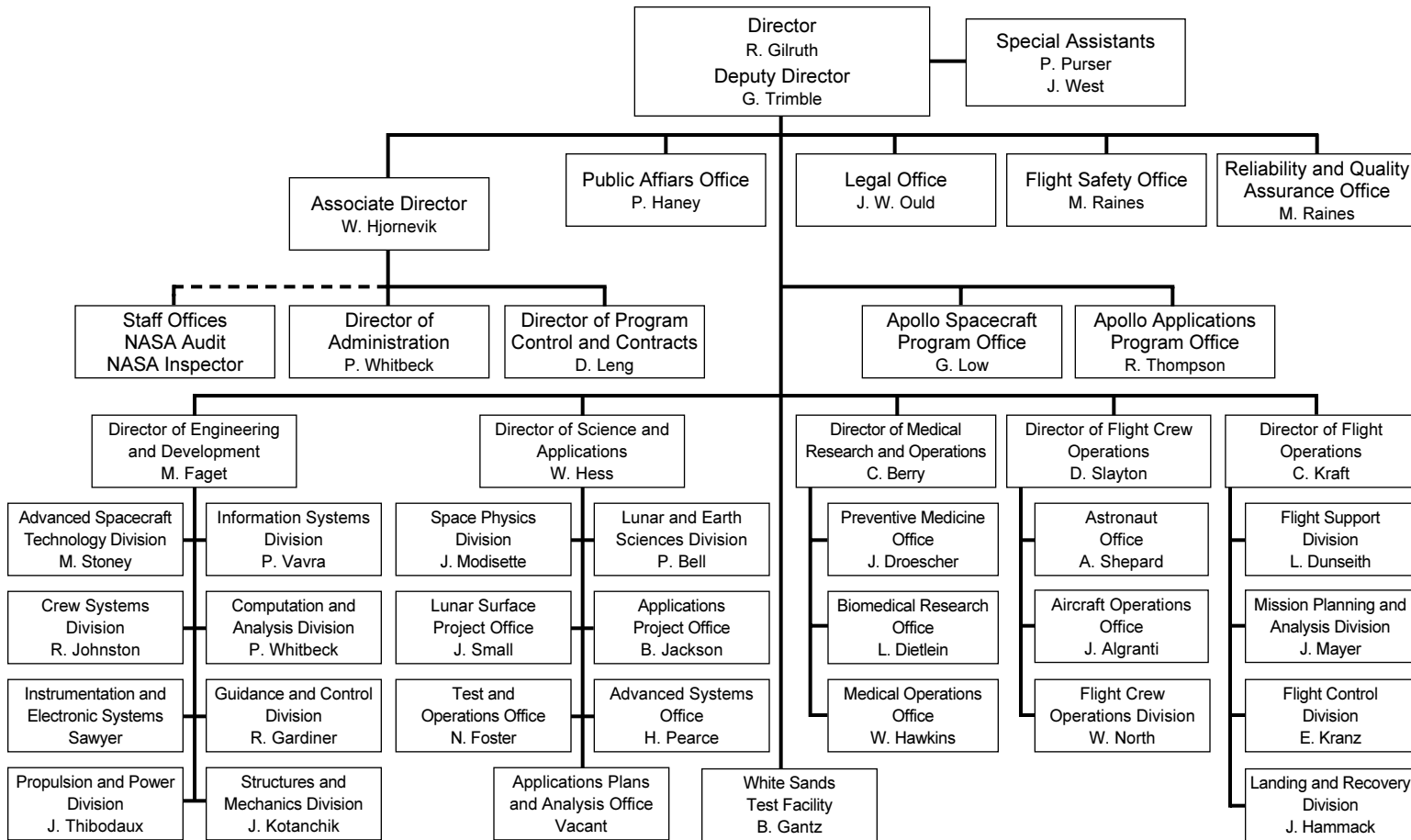


FIGURE 12. Operations-oriented Divisions as of June 1968



The Apollo 8 lunar flight marked a giant step toward NASA's lunar landing. Here, Clifford E. Charlesworth, the Apollo 8 "Green Team" Flight Director, is seated at his console in the Mission Control Center.

never been used. Moreover, directing a vehicle from one moving celestial body to another involved what Ron Berry called "a fascinating (but difficult and complex) bit of math, physics and geometry." But Owen Morris and others, were "targeting junkies."¹⁹ And some very helpful data had been secured within the past few years from unmanned probes to the lunar surface.

Although there had been a number of earlier Ranger misadventures, Ranger 7 sent the first high-resolution photographs of the lunar surface back to Earth in 1964. The success of Rangers 7, 8, and 9, from July 1964 through March 1965, provided data on the size and distribution of lunar craters and boulders. In May 1966, Surveyor 1 successfully soft-landed on the Moon, confirmed the bearing strength of the lunar soil, and returned thousands of images. By February 1968, five of seven Surveyors successfully landed and confirmed the suitability of several Apollo landing sites. During 1966 and 1967, five Lunar Orbiter missions carrying high-resolution and wide-angle cameras helped in mapping 97 percent of the Moon's surface. While the Ranger, Surveyor, and Lunar Orbiter unmanned flights provided hard data and encouraged confidence, there were still nagging uncertainties about a lunar voyage. Many speculated that simply leaving the Earth's gravity could cause serious illness. Others worried that returning astronauts could return with contaminants that might endanger human life and Earth's ecology. In spite of these concerns, Leland Atwood's (North American) endorsement of the mission at the Apollo Executives meeting probably reflected the views of most: "This is what we came to the party for."²⁰

Apollo 8 flew as scheduled on December 21, 1968, carrying Frank Borman, James A. Lovell, Jr., and William A. Anders on 10 orbits around the Moon. The entire mission was conceived, planned and "trained for" in a 6-month time frame. Gerald Griffin, one of the mission flight control directors, remembers that Apollo 8 "was kind of scary. It pushed the system faster. It showed an ability to take risks." As for Kranz, at first the Apollo 8 lunar

flight decision “irked the hell” out of him because it confused and set aside the careful planning and training for the Apollo flight schedule. He complained to Chris Kraft, but he wasn’t asked to vote, he said. But the Apollo 8 lunar decision, Kranz added, involved the “management of risk.” It meant, in effect, taking a greater risk then in order to reduce risks in later flights.²¹ Most of those who returned to Johnson Space Center in July 1989 to celebrate the 20th anniversary of the lunar landing of July 1969 concurred that Apollo 8 made landing in that decade possible.

But Apollo 8 was an uneasy flight. Charlesworth remembers, preparations for the flight were difficult, “but we launched.” The astronauts made two orbits of Earth before burning the S-IVB for translunar trajectory, but the trip out “was not uneventful.” We decided to test the engine on the way out to be sure it was working right “and it did not work right!” Everyone

in Mission Control rushed to deal with the engine. As tension mounted, one of the astronauts reported being ill. A “sick astronaut committee,” which included Gerry Griffin, turned to deal with this problem, but feared that indeed the sickness might be caused simply by leaving Earth’s gravity, and thus would be incurable. Concentrating wholly on the engine problem, Charlesworth thought the astronaut should “be sick and be quiet about it.”²²

Charlesworth and everyone in Mission Control worried that the engine either might not fire or might not fire correctly for the lunar orbital insertion. If it did not burn correctly, a return to Earth might be impossible. Tension was “thick enough to cut with a knife” Chris Kraft remembers. But the lunar orbit insertion burn worked. Then, Mission Control personnel were “spooked” when Apollo disappeared behind the Moon. But it came back around and made 10 “hard work” orbits around the Moon, before a successful engine burn headed the Apollo home to Earth and a safe landing.²³ Apollo 8 was one of the most significant lunar flights. It resolved many of the unknowns and accelerated the entire lunar landing effort.

It created “an astounding international awakening” commented Owen Morris, who headed the Lunar Module Engineering Division Management team under George Low. Perhaps it was in the understanding that humankind stood closer than ever before to the unknown and the creative processes of the heavens and the Earth, that the astronauts aboard Apollo 8, led by Frank Borman, elected to read from lunar orbit on Christmas eve the first 10 verses of Genesis: “In the beginning God created the heaven and the earth. And the earth was without form, and void . . .” God created from that the land and the sea, and darkness



MSC Director Robert R. Gilruth and Flight Operations Director Christopher C. Kraft monitor Apollo 9’s Earth-orbital mission of March 1969.

and light. “. . . and God saw that it was good.”²⁴ The text might have included that one day men would walk upon other heavenly bodies.

While it received less public attention than the lunar flights, Apollo 9, which flew an Earth-orbital mission in March 1969, was one of the most interesting of all Apollo flights. Apollo 9 made the first flight test of a manned LM. Kranz, who assigned flight directors, assigned himself to those flights closely associated with LM operations, including Apollo 5 (the first unmanned LM flight), 7, 9, 11, and 13. Apollo 9 was the first time that flight controllers operated a dual system—that is, one separate flight operation with the command module and concurrently another with the LM. The communications load, workload, and problem trouble-shooting load now doubled.²⁵

The nice thing about Apollo 9 was that there was a lot of free time to experiment and get acquainted with the systems. During Apollo 9 operations, the Mission Control teams established procedures for use of the LM as a lifeboat, tested engine burns, and tried lowering every function of the command module and the LM to their lowest possible level—malfunction procedures which later proved invaluable during the Apollo 13 flight. Kranz felt intrigued by the keen sense of competition between North American contractor representatives and flight controllers and Grumman contractor representatives and flight controllers, and by the general level of excitement.²⁶ With a lunar landing now a tangible reality, the excitement and energy level of all those associated with NASA and the Apollo programs rose precipitously.

The LM was the first vehicle built for humans for nonterrestrial use. There was little engineering and design history to work from, other than that provided by Earth-orbital flights and unmanned lunar vehicles such as Ranger and Surveyor. Surveyor, incidentally, made significant design contributions, especially to the landing gear and Doppler radar systems. Using existing knowledge, managing engineers completed the Statement of Work for LM in June 1962. The Request for Proposals, released in July, produced nine proposals. North American, which held the primary contract for the Apollo spacecraft, was precluded from the competition—over the company’s strong objections. McDonnell Aircraft chose not to enter the competition. After some delays and reviews precipitated in part by the President’s Science Advisory Committee, NASA awarded the LM contract to Grumman Aircraft Engineering Corporation of Bethpage, New York. The cost-plus-fixed-fee contract for \$387.9 million (including the Grumman fee of slightly over \$25 million) was signed by NASA and Grumman on January 14, 1963. Constant changes engendered in part by the experimental and innovative nature of the product being manufactured, changes in specifications, production delays, subcontracting problems, and cost overruns resulted in costs reaching \$1.42 billion.²⁷ Perhaps because of the remarkable achievements of the LM, those cost overruns failed to provoke a public or congressional protest.

Engineering guidelines provided that although there would be no provision for in-flight repair, redundancy (or backup systems) would be sufficient to assure that “no single failure can endanger crew safety.” In addition, low weight was an “ultimate premium” in design and construction decisions. Each pound of inert weight lowered to the lunar surface and returned to the command ship required an additional 3.25 pounds of propellant. Each pound of LM weight then, added 4.25 pounds to the payload of the Saturn-Apollo system, with commensurate fuel requirements for the Saturn V (resulting in approximately 50 pounds of added weight for each pound of inert weight lowered to the Moon).²⁸

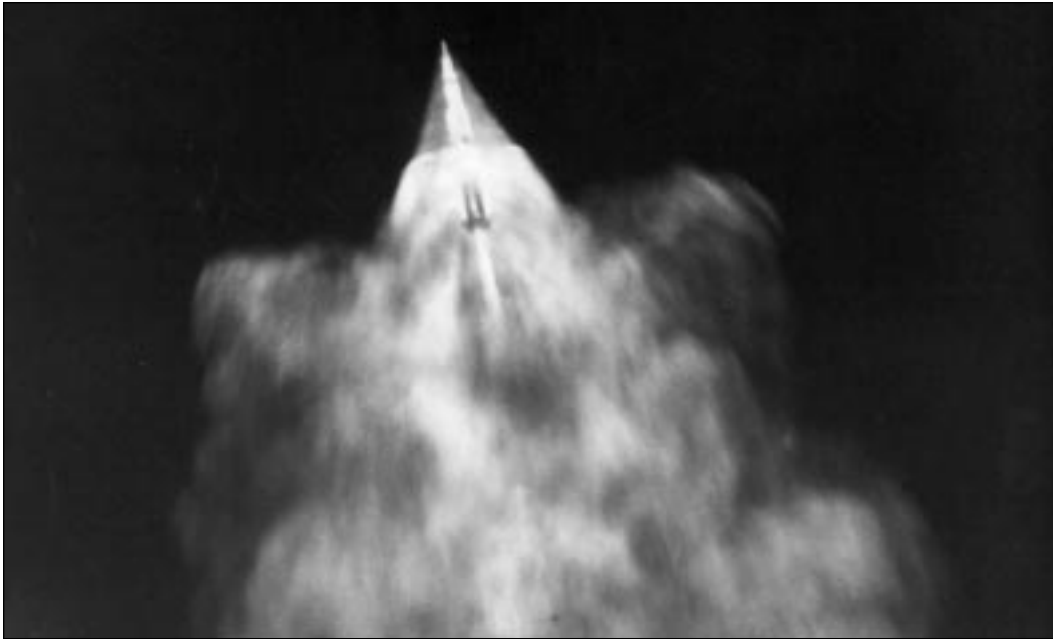
Although LM construction encountered many delays, including that caused by the AS-204 fire, by July 1967 Grumman announced that the vehicle would soon be assembled and ready for flight testing. Grumman, as did North American for Apollo, served as the primary contractor for the LM and used many subcontractors. Space Technology Laboratories, Inc. (STL) and Rocketdyne both worked on rocket engines with a throttle control system; and Manned Spacecraft Managers, in a rare reversal of a primary contractor's decision, selected STL for the throttleable LM descent engine. Bell Aerosystems produced the ascent engine, and Hamilton Standard Division of United Aircraft developed the environmental control systems. Although NASA substituted batteries for LM electrical power, Pratt and Whitney (a division of United Aircraft Corporation) developed the electrical power fuel cells (then a very advanced technology). RCA produced the rendezvous and landing radar systems. Other Grumman subcontractors included TRW/STL, the Allison Division of General Motors, Radiation, Inc., Marquardt Corporation, General Precision, Inc., and the Garrett Corporation.²⁹

Low strengthened the coordination of the LM and command module projects in 1967 by appointing a resident manager from his Apollo Program Office at MSC to North American. Wilbur H. Gray became the Resident Manager to North American Aviation in Downey, California. Kenneth S. Kleinknecht was made Manager of the Command and Service Module for the Apollo Spacecraft Project Office under Low at MSC, and Dr. William A. Lee, formerly an Assistant Project Manager, received responsibility for the LM, with specific authority over Grumman's design, development, and fabrication of the module.³⁰

Another unique "tool" of the lunar missions was the specially designed "extra-vehicular mobility unit," or the astronauts' space suit and battery-powered backpack, which provided a cooled and revitalized atmosphere in which to live. Although obviously similar to and drawing upon EVA experiences from Gemini, lunar suits were much more complex because of the enhanced active cooling system required. Production of a suitable lunar suit proved correspondingly difficult. An initial production agreement between Hamilton Standard and International Latex Corporation failed to produce a suitable lunar suit. While testing continued with the Gemini suits, new competition for an Apollo space suit between Hamilton Standard (with B.F. Goodrich), David Clark Company (which developed the Gemini suit), and International Latex resulted in Hamilton Standard retaining the "backpack" contract while International Latex developed the suit on an independent contract—and the MSC provided systems integration.³¹ In a word, a lunar mission involved many untried tools and operational techniques.

Apollo 10, launched May 18, 1969, carried humankind one step closer to the Moon. The command module named *Charlie Brown* and the LM called *Snoopy* completed 31 lunar orbits and successfully demonstrated crew support systems and operational procedures aboard the command and lunar modules. Eugene A. Cernan, who with Thomas P. Stafford and John W. Young flew Apollo 10 and accomplished a separation and rendezvous with the LM while in orbit, reflected that the greatest thing he brought back from his flight was simply the "feeling and the majesty" of it all. Earth, he said, "is overpoweringly beautiful."³²

On July 16, Apollo 11 left Earth for a mission to land men on the Moon. The two previous lunar orbital flights and the imminent lunar landing awakened among the astronauts and many of those who participated in the programs, and among the general public who



This shot of the Apollo 11 launch taken at 40,000 feet at 9:32 a.m. on July 16, 1969, from Air Force EC-135 captures the surrealistic image of the 7.6 million pound thrust Saturn V first-stage booster just prior to separation of the S-1C stage. Apollo 11 is the first NASA lunar landing mission.

merely observed from a distance, a new perspective of life in the universe. It denoted an awakening perhaps not unlike that triggered by Copernicus's realization that Earth was indeed not the center of the universe, but that Earth was one of many heavenly bodies that revolved about one of perhaps many suns. It was an awakening that Michael Collins shared

with the world. Collins, who flew the command module during the Apollo 11 lunar landing, put it rather simply, "A lot of the things we thought were not important—really are!"³³



The big moment! George M. Low watches a television monitor during the lunar surface EVA of astronauts Neil A. Armstrong and Edwin E. Aldrin, Jr.

For those with Gene Kranz in the Mission Control Center that was an understatement. No thing in lunar flight was unimportant. The training for the Apollo 11 lunar landing mission was particularly rugged. "Nothing we do today (said Kranz referring to the Shuttle missions in 1990) can compare." As crews became more experienced, discipline tightened rather than relaxed. The simulated lunar training missions had almost been clairvoyant, but the mission was fraught with peril and

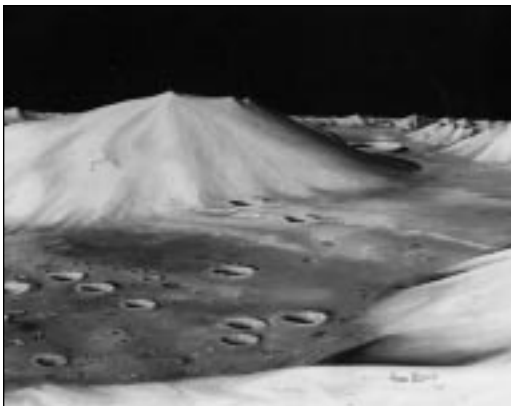


Tensions remained high throughout the 195-hour Apollo 11 lunar mission. Here Flight Director Clifford E. Charlesworth (center) and Eugene Kranz (to his left) prepare for the change of shifts.

problems and those problems took everyone's mind off the fact that "we were landing on the Moon."³⁴ Mission Control's job was to solve problems and there were plenty to solve.

Just prior to the lunar landing attempt, Gene Kranz gave a speech to the Mission Control crew that Steve Bales thought "Patton would have been proud of!" Kranz told them that the success of the mission depended on them, and he had every confidence in them. Then he locked the doors to Mission Control and the flight control crew became even more concentrated and intent on their work.³⁵

As Apollo made its final orbit of the Moon, the LM, named the "Eagle" by its two-man crew Neil Armstrong and Edwin Aldrin, separated nicely from the mother ship on the back side of the Moon. But when the command module cleared the Moon and communications resumed with Mission Control, communications and telemetry between Mission Control and Apollo were bad. At this point Mission Control had about 5 minutes in which to abort a lunar landing. After a careful check of all systems, Kranz decided to continue. Then, with the *Eagle* 4 minutes away from its landing, the crew discovered that the LM's altimeter and velocity gauges were in error. Those problems were corrected. Next, the crew reported a computer alarm. A quick flight control analysis resulted in a "judgment call to continue." Concentration throughout the Mission Control Center was intense. One final abort option existed in the last 27 seconds of the flight. In that brief time, a complete status check through all of the Mission Control desks cleared the *Eagle* for a landing. But even then, as the *Eagle* prepared to set down, Neil Armstrong was forced to



These artist depictions of the lunar surface and a lunar landing reflect a new awareness by Americans of non-terrestrial bodies.



A view of Mission Control Center during Apollo 11 EVA.

override the planned landing program in order to avoid rocky and dangerous terrain at touch-down. But the *Eagle* did land. For a time NASA was not sure just where.³⁶

The first real sense Kranz had that the lunar landing had been completed was when he noticed people in the Mission Control viewing room cheering. Suddenly, the flight control team lost concentration. At that moment of stunned realization, Kranz simply stopped thinking.³⁷ But thought and work resumed quickly as the flight control crew replacement shift came on duty.

President Richard M. Nixon flew to the recovery area in the central Pacific to welcome the Apollo 11 crew upon the completion of the historic mission. President John F. Kennedy's 1961 charge to put an American on the Moon within the decade and return him safely to Earth had been achieved.





Apollo 11's lunar module casts a long shadow upon the Moon and symbolically upon the future of Earth.

Clifford E. Charlesworth replaced Kranz as Flight Control Director for the “lunar surface shift.” Already a new problem was on the floor. Mission Control was anxious to take advantage of every spare minute on the Moon’s surface. Mission planning included two “activity” options once the *Eagle* landed. One, favored by the medical teams, was for the astronauts to rest and sleep; the other, favored by Mission Control on the premise that the astronauts would be unable to sleep, called for an EVA on the Moon’s surface. The debate raged in the control room. Armstrong, on the Moon, put in his two cents worth; “sleep now just doesn’t make

sense.” So the astronauts and Mission Control won. When the EVA did come, Charlesworth was very nervous, and it was a relief to have the astronauts back in their pressurized cabin.³⁸

Tension heightened as the *Eagle* prepared for the lift-off from the Moon’s surface and the rendezvous with Collins in the Apollo command module. Glynn Lunney took over the lunar orbit return “watch” from Charlesworth. Although he defined the flight control job as one that depended wholly on the kind of decisions that had to be made (and which required instant and programmed responses), Lunney regarded lift-off as something different. There were really no decisions to make. Either the ascent engine worked or it didn’t. “We thought we knew how to handle the rendezvous.”³⁹ And of course they did. Apollo 11 brought two men to the surface of the Moon and returned them safely to Earth.

Paradoxically, following that great moment of triumph, some subtle but disturbing cross-currents developed which would follow NASA for the rest of its days. President John F. Kennedy’s 1961 call for America to land a man on the Moon and return him safely to Earth within the decade had been achieved. Narrowly construed, there was nothing more to do. Some Americans, perhaps skeptical, cynical, or disturbed about the concurrent costs of war, welfare, and space, believed that society might benefit more in the short term from war or welfare than from expensive flights in space. Although Lyndon Johnson personally supported NASA from the time of its creation, by 1964 and increasingly through 1968, his administration put pressure on NASA to reduce expenditures lest growing federal expenses for the war in southeast Asia, social programs at home, and space overheat the economy. President Richard M. Nixon continued to cite those budgetary pressures as inflation added to the rising financial crises. Had the commitment to space been too narrowly defined? Was the mission complete? NASA continually tried, but could never satisfactorily explain, “Why go further?” Although projects such as Skylab and the Shuttle were under development, NASA had difficulty justifying those programs and explaining what would be next after Apollo. NASA, to be sure, was almost totally preoccupied with its present mission and successes. Spaceflight, for most NASA personnel and contractors, needed no justification more elaborate or sophisticated than that of Michael Collins: “We are wanderers.”⁴⁰ But there was more.

No single event in the history of the world has raised the prestige of any country such as the Apollo program has,” commented William B. Bergen, President of North American Rockwell. When President Nixon “took off on his trip around the world immediately after Apollo 11 . . . no matter where he went, the main thing in peoples’ minds around the world was, this is not President Nixon of the United States. This is President Nixon of that country that put the fellows on the Moon!”⁴¹ The lunar landing of July 1969 gave the American people a shot of adrenaline and a resurgence of faith after a long and bruising succession of real and imagined cold war adversities. NASA, MSC, and personnel in Mission Control were little short of ecstatic. Apollo 11, most thought, was only the beginning.

“What we did after Apollo 11,” reflected Gerald Griffin, Flight Control Director for Apollo 12, “was nothing short of fantastic.” Problems of a stratospheric dimension literally struck Apollo 12 during launch from the pad at Kennedy Space Center on November 14. Lightning struck the spacecraft during the launch, and although the Saturn V continued flawlessly, the Apollo electrical systems failed. There had been no planning or simulations for such an event. Kraft came to the control room and advised Griffin, “Young man, we don’t have to go to the Moon today.” When Griffin ran a systems check, John Aaron, then a 25-year-old recent graduate of Northeastern Oklahoma University, asked the astronauts to reset the fuel cell relay switches. When they did, the lights came on again. Aaron then recommended that Apollo make an extra Earth orbit while the regular scheduled lunar orbit check list was reviewed. After the review, all systems were go, and the flight completed its lunar mission in spectacular fashion. As Glynn Lunney said later, “Aaron was the right person at the right time in the right place. Griffin and the entire flight control crew did a great job.”⁴²

Once the systems check was made Griffin urged the others to “get on with it,” and the Saturn-IVB thrusters pushed the vehicles toward the lunar destination. After separation of the lunar craft, Richard F. Gordon piloted the command module *Yankee Clipper* on a total of 34 lunar orbits. The LM, called *Intrepid* by its crew, landed on target in the Ocean of Storms, 182 meters from the Surveyor 3 unmanned spacecraft. Alan L. Bean, the LM pilot, and Charles Conrad, flight commander, spent 31 hours on the Moon’s surface, 7 of those in EVA. They walked about collecting samples of rock and photographing the surface—and the Earth as it had never been seen before. They hiked over to the Surveyor, examined it, photographed it, and brought back a camera and smaller parts for study. They collected 34 kilograms (about 75 pounds) of lunar rocks and brought them back to Earth.⁴³

Astronaut Joseph P. Allen, who worked the Apollo 12 flight as the Capsule Communicator, had the occasion to scold his son (then only 3 years old) shortly after the Apollo 12 flight: “Why are you dumping dirt on the kitchen floor?” The child replied: “these are Earth rocks, not dirt.”⁴⁴

More than any other discovery or phenomenon, the Moon rocks signified the scientific portent of the lunar expeditions. Because of the tremendous emphasis put on performing operations, science appeared to have been relegated somewhat to the back seat of NASA’s Apollo program. The stress that developed between the scientific community and the engineering community at the inception of the Mercury program, never fully dissipated through the Gemini and early Apollo flights, despite efforts within and without NASA to obtain a better accord and accommodation. Many scientists thought that spaceflight, with its heavy developmental focus, neglected the sciences and siphoned federal funds from science

programs. The apparent imminence of a lunar landing brought into sharp focus within NASA and the scientific community the opportunities and responsibilities commensurate with a lunar expedition. The dialogue (previously mentioned) over how to handle lunar materials and design a Lunar Receiving Laboratory signaled a quickening of scientific involvement in space operations. Until at least 1967 “getting there” reflected the major dynamics of the Apollo program. But what happened once you got there? A flag raised? A salute? Moon rocks? Or more?

The status of science within MSC rose measurably as the understanding of the Apollo program began to go beyond a physical landing on the Moon. In January 1967, Center Director Bob Gilruth removed the old and sometimes ignored Space Science Division and Experiments Program Office from the Engineering and Development Directorate, and upgraded the office to an independent and co-equal Science and Applications Directorate. The new office, Gilruth explained, “reflected the growing significance and responsibilities of the center in these areas” and “will act as a focal point for all MSC elements involved in these programs, and . . . provide the center’s point of contact with the scientific community.” He appointed Robert O. Piland, who had been managing the Experiment Program Office, as the Deputy Director while searching for a scientist to head the new directorate.⁴⁵

The Science and Applications Directorate comprised a Lunar and Earth Sciences Division which was itself compartmentalized into two segments. John Eggleston, designated as the special assistant to the director, focused on scientific experiments and applications. A mapping sciences branch and a geophysics branch reported to Eggleston. The Lunar Receiving Laboratory, with Joseph V. Piland (Bob Piland’s brother) serving as acting manager, was operated by the various branches of the Lunar and Earth Sciences Division. The Geology and Geochemistry Branch had responsibility for the lunar sample laboratory and functions related to astronaut geology training, mission simulation, lunar surface definition, and scientific lunar surface hardware or tools. The Biomedical Branch controlled quarantine, medical and bioscience functions of the Lunar Receiving Laboratory, and the Engineering and Operations Branch provided the detailed operation, planning and program control functions of the laboratory. The Mapping Sciences Branch and the Geophysics Branch reported to Eggleston and retained more of an operations rather than scientific orientation.⁴⁶ Although some embittered scientists thought in some respects it was a belated reorganization with only a “scientific flavor,” the new directorate facilitated the scientific work which became particularly significant during the flights of Apollo 14 through 17.

On February 17, 1967, Gilruth appointed Dr. Wilmot N. Hess to head the Science and Applications Directorate. Hess came to MSC from Goddard Space Flight Center where he had served as Chief of the Laboratory for Theoretical Studies. Before that he was a nuclear physicist on the teaching and research staff of the University of California and headed the University’s Lawrence Radiation Laboratory at Livermore, California, before joining NASA in 1961. His reputation came largely from his work in high-energy nuclear physics, neutron scattering, cosmic ray neutrons, and studies of the Van Allen radiation belts.⁴⁷

Dr. Hess and scientific projects sometimes conflicted with engineering and flight operations objectives. Engineers wanted to be sure their machines could fly to the Moon before they became too concerned about what would happen once they arrived. Operations people wanted their best pilots at the controls of those machines. Scientists began to suspect

that the scientist-astronauts recruited earlier for the Apollo missions were being systematically excluded from flights in favor of test pilots. Although Hess and the new Science Directorate helped tilt the last three Apollo flights toward a strong science profile, Apollo continued to be an elaborate exercise in flight operations.

There were several significant characteristics of the personnel who comprised the operations teams. As Gerald Griffin observed, “we were a bunch of young people, most of us in our twenties and thirties. We had more responsibility at age 30 than most people will have in a lifetime.” Kranz, who headed the Flight Operations Division, was extremely thorough and disciplined, thought Griffin, and the Mission Control room always ran in a very businesslike atmosphere.⁴⁸

During the mission, the flight director made all real-time decisions. This unwritten rule seemed threatened, Kranz recalled, when Headquarters began assigning mission directors (such as William C. Sneider, Chester M. Lee, Thomas H. McMullen, and George H. Hage) to the control room during Gemini flights. Some of these on occasion “walked in and tried to take over,” but most properly served their role as observers. During one flight, Kraft became extremely upset when the Headquarters Mission Control representative attempted to intervene in a flight director’s decision. A “mission directive” from Sam Phillips subsequently made the mission director a broker for broad policy decisions only between Headquarters and the center. Longer-term flight decisions were made by the flight director in consultation with the mission director and other appropriate offices.⁴⁹ Mission Control, in actuality, involved a synchronized response by hundreds of operators and managers.

The operating stations in the Mission Control Center physically surrounded the flight director’s console. To the right of the flight director, the CapCom (or capsule communicator—always an astronaut) relayed voice information and instructions to the astronauts from Mission Control. A guidance officer (who monitored onboard navigation and computer control systems) collaborated with the flight dynamics officer (FIDO) in planning maneuvers and trajectory. A booster systems engineer; propulsion systems engineer; guidance, navigation and control systems engineer; electrical, environmental and consumables systems engineer; and instrumentation and communications system engineer monitored their respective systems and provided a liaison with contractor and engineer support groups in a myriad of staff support rooms located throughout Building 30 (and beyond, if needed). A ground control officer coordinated tracking and data information with Goddard Space Flight Center, while a computer supervisor had responsibility for Mission Control hardware and software. The flight surgeon monitored the crew’s health and provided personal counsel. A space radiation analysis group provided constant readings and recommendations for the surgeon. Mission rules established procedures for solar flares and major radiation phenomena. The public affairs officer provided a continuous commentary and linked the flight to the news media and the public. Brian Duff, who replaced Paul Haney as public affairs officer, over considerable opposition convinced Gilruth that reporters should be admitted into the Mission Control Center during missions for in-flight press conferences. The position reconfirmed NASA’s open access policies, but also created a potential public relations problem when things went wrong. A display board, similar to that found in a battleship’s “war room” (combat control center) provided constantly updated data and flight positions superimposed on a world chart. All of these information systems and personnel were

Suddenly, Tomorrow Came . . .

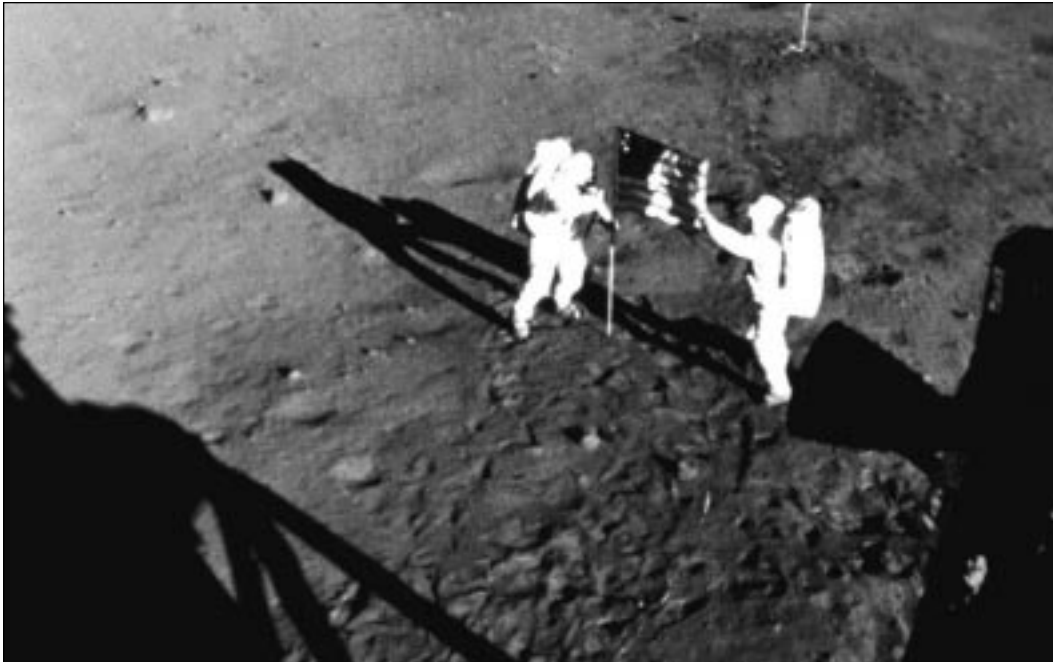


An imprint destined to permanently alter human affairs—a simple human footprint on the lunar surface.

immediately responsive to the flight director. Mission rules one through six, Steve Bales said, were that irrespective of what the other rules stated, the flight director “may do whatever is necessary to complete a successful mission.”⁵⁰

During the flight of Apollo 13, the flight director and flight control team faced extraordinary crises. Glynn Lunney, who directed the Apollo 11 return flight, recalled Apollo 13, launched April 11, 1970, as the ultimate test in dealing with a problem.” The third lunar mission, carrying astronauts James A. Lovell, Jr. (mission commander), John L. Swigert, Jr. (command module pilot), and Fred W. Haise (lunar module pilot) lifted off in something of an already “routine” fashion from the pad at Cape Kennedy. The flight, to be sure, had experienced a preflight problem. John Swigert stepped in to replace Thomas K. Mattingly 24 hours before lift-off, when the flight surgeon determined that Mattingly had been exposed to the measles. Swigert called Mission Control from space to ask someone to mail his tax return for him before the April 15 deadline. And there had been a problem in emptying and refilling one of the oxygen tanks in the service module. Other than that, the trip out was going fine. Things went well until the third day as the craft approached the Moon. Then, Jim Lovell remembered, “I heard a loud hiss-bang.” An alarm light came on the control panel. Then two more lights. Then others. “A wave of disappointment swept through the spacecraft. We were in deep trouble.”⁵¹

An oxygen tank in the service module—which affected oxygen, water, and electrical supplies in the command module—exploded. The second of the two oxygen tanks began losing pressure. The command module, which housed the three astronauts, was about to lose



Millions of people around the world were awakened to a new perspective of life in the universe when astronauts Neil A. Armstrong and Edwin E. Aldrin landed on the Moon and raised the flag.

its oxygen, water, and electrical supply. Water for consumption was important, but water for cooling the electrical equipment was critical. The mission and the astronauts were in very deep trouble. Kranz and the Mission Control team conducted a quick but thorough assessment of the situation. The first problem was to check the instrumentation to be sure that the readings being received were accurate. The second effort was to try to preserve what was left of vital supplies of water, oxygen and electricity. This involved a program of “progressive downmoding”; that is, eliminating all unnecessary consumption, step by step, but analyzing each step to see how it might affect the operation and living environment. It was a process, Kranz said, of “orderly retreat.”⁵²

Almost fortuitously, during the long “practices” by Mission Control with the Apollo 9 Earth-orbital flight, the flight control team headed by Kranz established procedures for using the LM as a “lifeboat.” They had also experimented with “throttling down” the command module. Fortuitously too, Kranz said, he had John Aaron, Arnold D. Aldrich, and Philip C. Shaffer analyzing the data. Mission Control shut down first one, and then the second fuel cell in the command module. The LM’s guidance system was then aligned with that of the command module in anticipation that the major guidance system would become inoperative. Then the astronauts were sent to their lifeboat while all systems in the command module were shut down. The LM had a very limited and fragile environment, and it too was held to minimum capacities by Mission Control.⁵³

Mission Control decided that course corrections using the service propulsion system could not be risked, in part because of the lack of electrical power, but also because of the risk

that the service module had been structurally weakened by the explosion. The descent propulsion engine of the LM would be used to put the crippled spacecraft into a return trajectory and to insert the craft into Earth's atmosphere. These were major problems. Minor, but equally deadly problems, such as the accumulation of carbon dioxide in the LM, constantly confronted the operators. The entire MSC and NASA organization rallied to the crisis:

When word got out that Apollo 13 was in trouble, off-duty flight controllers and spacecraft systems experts began to gather at MSC, to be available if needed. Others stood by at NASA centers and contractor plants around the country, in touch with Houston by telephone. Flight directors Eugene Kranz, Glynn Lunney, and Gerald Griffin soon had a large pool of talent to help them solve problems as they arose, provide information that might not be at their fingertips, and work on solutions to problems they could anticipate farther along in the mission. Astronauts manned the CM and LM training simulators at Houston and at Kennedy Space Center, testing new procedures as they were devised and modifying them as necessary. MSC Director Robert R. Gilruth, Dale D. Myers, Director of Manned Space Flight, and NASA Administrator Thomas O. Paine were all on hand at Mission Control to provide high-level authority for changes.⁵⁴

Gene Kranz remembers that following the successful burn to put the spacecraft on a free-return trajectory to Earth, three MSC Directors—Deke Slayton (Flight Crew Operations), Chris Kraft (Flight Operations), and Max Faget (Engineering and Development) offered varying procedural advice, which ranged from Slayton's concern that the crew needed sleep and rest, to Kraft's concern about power consumption, to Faget's concern about heat control. Finally, a decision was made to turn the astronauts to work on a program for passive thermal heat control. When those attempts failed, the entire procedure was reset and this time it worked!⁵⁵

Words can never wholly recapture the thought processes, analyses, energy, and emotion that went into the return of the endangered Apollo 13 astronauts. On April 17, the astronauts left their sanctuary in the LM and returned to the crippled Apollo CM for the reentry, jettisoning the LM. Operating on battery power alone since the explosion, the Apollo command module reentered the atmosphere and landed the weary and chilled astronauts within a mile of their recovery ship, the *Iwo Jima*. "If I had to explain our success," Kranz reflected years later, "it had to be the confidence in our own management."⁵⁶

Thus, before the close of the decade of the 1960's, NASA had designed and its industrial contractors had built machines that could successfully take humans to the Moon and return them safely to Earth. NASA astronauts and operations personnel learned to fly those machines and to respond to the constant problems and surprises that spaceflight brought. Moreover, they developed the discipline and the systems to respond to problems. Spaceflight put Americans on a new and steeply graded learning curve. Spaceflight tested machines and human mettle and intellect under conditions and in an environment never previously encountered.

Thus far, not one but two machines had landed people on the surface of the Moon and returned them safely to Earth, and three more machines had carried humans in orbit around and behind the Moon and returned them safely as well. During the next 2 years

Apollo made four more successful flights and landed astronauts and their increasingly sophisticated equipment on the lunar surface. And then Apollo never again flew to the Moon.