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Chapter 22

Apollo Scientific Exploration of the Moon[1]

Wm. David Compton[2]

President John F. Kennedy's decision to make a manned lunar landing the foundation for the United States' space program owed nothing to any scientific interest in the Moon. The main purpose of Project Apollo was to restore the nation's prestige, which, in the opinion of many, had seriously declined as a result of the Soviet Union's early successes in space flight. Equally important, the technological advances, facilities, and organization necessary to send men to the Moon and back would give the U.S. the capability to operate in space for whatever purposes suited the national interest. Finally, the very difficulty of landing men on the Moon appealed to Kennedy's conviction that a commitment to great things would be good for the nation's soul. In proposing the lunar landing to Congress he justified his choice, in part, on the grounds that no other space project would be "so difficult or expensive to accomplish,"[3] and in a speech a year later he remarked, "we choose to go to the moon in this decade and do the other things, *not because they are easy, but because they are hard*" [emphasis added].[4]

Even before Apollo, however, many Americans disagreed with the growing emphasis on man in space, among them several prominent scientists. During President Eisenhower's administration, the President's Science Advisory Committee asserted the pri-

[1] Presented at the Twenty-Second History Symposium of the International Academy of Astronautics, Bangalore, India, 1988. This paper is based on research conducted under contract NAS9-16646 with NASA Johnson Space Center for a history of the exploration phase of Apollo (now in press). Views and conclusions expressed herein are the author's and do not necessarily represent those of the National Aeronautics and Space Administration or the Johnson Space Center.

[2] Independent historian, Houston, Texas.

[3] *Public Papers of the Presidents: John F. Kennedy, 1961*, pp. 403-405.

[4] White House press release, 12 Sept. 1962.

macy of scientific goals in space exploration.[5] James R. Killian, science advisor to Eisenhower, declared that the space science program was of more lasting importance than manned space exploration.[6] Kennedy's science advisor, Jerome Wiesner, urged the president in 1961 to exploit the nation's lead in scientific space studies rather than spend large sums on manned projects, which seemed to offer little hope of early success.[7]

The American scientific community had strong reservations, to say the least, about the suitability of Apollo as a project for space exploration. The earliest space projects had opened a fertile new field to scientific inquiry, and the National Aeronautics and Space Administration (NASA) had supported it generously, creating a constituency of scientists whose investigations did not require man's presence in space. Some scientists appeared to feel that because space exploration had been initiated for scientific purposes, science had a prior claim to space—and to the funds that supported space programs. Others made the more reasonable argument that the really important knowledge to be gained in space could best be acquired by instruments, and the enormous cost of supporting man in space could not be justified by the meager contributions man could make to scientific investigations. In the summer of 1962, a group of scientists, convened by the Space Science Board of the National Academy of Sciences to review NASA's space science programs, reluctantly endorsed the Apollo project but they recommended that scientific exploration of the Moon should become the major aim of manned lunar expeditions as soon as the technological and operational problems had been solved.[8]

Congress and the nation, however, supported Apollo not for its scientific promise but for its stated objective, achieving superiority in space for the United States. A substantial minority felt that the project was given too high a priority on the national agenda, but that opinion had little effect, at least in the earliest days of manned space flight.

Science and Manned Space Flight

The fundamental dichotomy of space exploration—unmanned vs. manned projects—appeared in the beginning: scientific investigations got a considerable headstart on manned space flight. The split was perpetuated by institutional factors as well. In November 1961, a reorganization of NASA Headquarters separated the Office of Space Flight Programs into an Office of Manned Space Flight (OMSF) and an Office of Space Sciences (OSS), reflecting the high priority of the Apollo project.[9] About the same time,

[5] President's Science Advisory Committee, *Introduction to Outer Space* (Washington, 1968), p. 6.

[6] James R. Killian, address to the M.I.T. Club of New York, 13 Dec. 1960; quoted in John M. Logsdon, *The Decision to go to the Moon* (Cambridge, Mass.: MIT Press, 1970), p. 6.

[7] "Report to the President-Elect of the *Ad Hoc* Committee on Space" (classified version), Jerome B. Wiesner, chmn., 12 Jan. 1961, p. 10.

[8] *A Review of Space Research*, National Academy of Sciences—National Research Council Publication 1079 (Washington, 1962), pp. 1-21 to 1-22.

NASA announced that the Space Task Group (created to manage Project Mercury) was to become a new organizational element called the Manned Spacecraft Center (MSC), responsible for developing all NASA's manned spacecraft and conducting manned flight operations. The new center was to be built on a site recently acquired near Houston, Texas.[10] This physical and organizational separation of manned space flight operations from other elements in NASA undoubtedly contributed to the difficulty of incorporating science into Apollo.

More important, however, was the sense of urgency that set the manned space flight program apart. On 25 May 1961, when the president set the lunar landing as its goal, NASA had only 15 minutes of manned space flight experience. Kennedy's challenge gave the space agency only 8-1/2 years to send men to the Moon and back. MSC's spacecraft engineers believed it could be done, but they knew it would require all their time and effort for the rest of the decade. They gave lower priority to tasks they considered secondary—such as planning for science.

In any case, planning for science was the responsibility of the Office of Space Sciences. Under Homer E. Newell, who directed NASA's science programs from the beginning, OSS was to a large degree an operational arm of the external scientific community. Its program was guided by a Space Sciences Steering Committee, composed of prominent scientists from outside the government, as well as NASA employees. OSS also periodically sought advice from the Space Science Board of the National Academy of Sciences.[11] For specific projects, OSS solicited proposals from outside scientists, subjected them to peer review, funded those selected for flight, and conducted flight operations. The only constraints imposed on the experimenter were those arising from limitations of the spacecraft or flight operations.

Manned programs, however, operated under different rules. The Office of Manned Space Flight had a unique mandate, and it answered to no outside professional community for the content of its programs. From 1961 onward, the lunar landing overshadowed all else, and operational considerations dominated the early manned projects. Newell and others tried to make a place for science in manned space flight, but neither OMSF nor space scientists were much interested at first. Problems of funding and of jurisdiction over instrument development had to be worked out. In late 1963, a Manned Space Science Division was created, reporting to both program offices, to coordinate such matters, and to provide a focal point for developing a manned space science program.[12]

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[9] Robert L. Rosholt, *An Administrative History of NASA, 1958-1963*, NASA SP-4201 (Washington, 1966), pp. 217-225.

[10] Stephen B. Oates, "NASA's Manned Spacecraft Center at Houston, Texas," *Southwestern Historical Quarterly* 67(3) (1964):355.

[11] Homer E. Newell, *Beyond the Atmosphere*, NASA SP-4211 (Washington, 1980), pp. 120-121.

[12] W. David Compton and Charles D. Benson, *Living and Working in Space*, NASA SP-4208 (Washington, 1983), pp. 60-61.

Developing a Lunar Science Program for Apollo

If, as Newell believed, man had a role in the scientific exploration of space, OSSA[13] had to construct a program that would effectively use the Apollo system to advance science's understanding of the Moon. To avoid appearing to dictate the content of such a program—which scientists would never tolerate—NASA solicited advice from many outside sources. The recommendations offered by scientists had to be reconciled with the limited resources of the space agency. Finally, a working relationship had to be established between scientists and engineers—two independent and somewhat touchy groups, each with its own concept of what could and should be done, and of who should be in charge. It was a slow and sometimes painful process.

When Apollo got under way, few scientists were interested in exploring the Moon. But, in early 1960, Homer Newell anticipated increased interest as space exploration matured, and established an office of Lunar and Planetary programs to manage research projects in those areas.[14] At the time the only active project was Ranger, which was planning an instrumented spacecraft to crash on the Moon, relaying television photographs as it approached.[15] The following July, the Surveyor project was created; it would build several larger, soft-landing spacecraft, equipped to collect physical and chemical data, as well as TV pictures to be relayed to Earth.[16]

Lunar scientists soon learned that Apollo was the dominating presence in space exploration. Both Ranger and Surveyor were subjected to strong pressure to provide data needed by Apollo spacecraft designers. Project scientists protested that their experiments would produce the necessary data in due course and were not inclined to change their plans.[17] The attempt to bend science to the requirements of an engineering project only intensified scientists' resentment of the priority given to Apollo, which, in the estimation of most of them, had insufficient scientific value to justify it.

Although engineering and operational problems dominated Apollo's schedule, manned space flight officials realized that it would be desirable to include as much science as feasible on Apollo missions. As the basic concepts of mission operations and spacecraft design emerged in 1962, they asked OSSA for advice on the content of the science program and recommendations as to the scientific training astronauts should have.

Like other federal agencies that supported basic research, OSSA always established scientific policy in consultation with the scientific community. On the matter of manned lunar exploration, the Space Sciences Steering Committee appointed an *ad hoc*

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[13] A reorganization of NASA Headquarters in 1963 transferred space applications projects (communications, meteorology, etc.), previously managed by an Office of Applications, into an Office of Space Science and Applications (OSSA).

[14] R. Cargill Hall, *Lunar Impact*, NASA SP-4210 (Washington, 1977), p. 38.

[15] *Ibid.*, pp. 18, 20-24.

[16] NASA, *Fifth Semiannual Report to Congress, October 1, 1960, Through June 30, 1961*, pp. 49-50.

[17] Hall, *Lunar Impact*, p. 114.

committee of NASA and academic scientists and charged it with defining broad boundaries. The committee first established general criteria for scientific exercises suitable for Apollo: experiments should be scientifically important, capable of being performed only on the Moon, significantly improved by having a man present, and likely to lead to advances in science and technology. They then suggested three basic types of experiments: measurements and observations to be made by the astronauts on the lunar surface, investigations to be conducted on samples returned by the crews, and instruments to be emplaced by the astronauts and left on the Moon to transmit data to Earth. As to crew qualifications, the committee felt that lunar explorers should ideally be professional scientists. As a minimum, however, the men who landed on the Moon should have enough background in the relevant sciences to recognize and appropriately act upon unexpected phenomena they might encounter.[18]

The committee submitted its report in July 1962, just after NASA chose lunar-orbit rendezvous as the operational mode for the Apollo missions. This decision defined a complex of hardware and mission plans that limited payload weights and the accessibility of various regions of the Moon—and thus, the scientific activity. That summer, NASA officials sought the opinion of a wider sampling of scientific opinion from a six-week study convened by the Space Science Board to review NASA's research program. A working group on the role of man in space exploration endorsed the *ad hoc* committee's recommendations and added some of its own. It urged NASA to recruit professional scientists for training as astronauts as soon as possible. Until qualified scientists were available, all Apollo astronauts should be given as much training in geology as possible.[19]

In early 1964, OMSF and OSSA began the process of developing the instruments and experiments for Apollo. First, a group of outside consultants was asked to identify the most important sub-disciplines within the fields already identified and to compile lists of eminent scientists who could formulate specific scientific tasks for the Apollo missions.[20] Shortly thereafter, several of these scientists were organized as Apollo science planning teams to consider what instruments and activities would produce the most valuable information as early in the program as possible.[21]

Meanwhile, mission planners at NASA's Manned Spacecraft Center had established a "reference trajectory" for the lunar landing mission—a detailed description of the flight from liftoff to splashdown. Specifications most important to science planning were the restrictions on landing sites, the allowable weight and volume of instruments and equipment, the time to be spent on the Moon, and the weight of samples to be returned.

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[18] "Minutes: *Ad Hoc* Working Group on Apollo Scientific Experiments and Training, 23 April 1962."

[19] *A Review of Space Research*, pp. 11-14 to 11-16.

[20] "Minutes: Manned Space Sciences Working Group of the Space Sciences Steering Committee," 30 Jan. 1964.

[21] *Ibid.*, 9 April 1964.

In mid-1964, MSC hosted a symposium at which scientists and mission planners compared requirements and constraints. At this stage, operational factors predominated, and the science planning teams re-worked their plans in light of these constraints. Their detailed report, submitted at the end of the year, was like many early science planning documents in including far more science than the project could carry out. It presented a lunar exploration plan stressing return of selected samples, emplacement of geophysical instruments, and field investigations around the landing site, which included estimates of weight, volume, and operating time required.[22]

In the summer of 1965, another summer study met at Woods Hole, Massachusetts, to advise NASA on directions for future space research. The Woods Hole study was more supportive of manned lunar exploration than the 1962 study had been. It put together a list of 15 broad scientific questions that lunar exploration should address, to shed light on the internal structure of the Moon, the processes that have altered its surface, and its evolutionary history.[23] Subsequent plans for lunar science were designed with reference to this list. After the meetings at Woods Hole concluded, a conference on manned lunar exploration met for two weeks at nearby Falmouth to recommend specific scientific work for Apollo and the emerging post-Apollo programs. Once more science planners outlined an ideal program that far exceeded NASA's ability to carry it out[24]; and again, it provided a scientific priority listing from which a realizable program could be extracted, within the limits of funds provided by Congress.

All plans for lunar science eventually had to be worked out with the Manned Spacecraft Center, which controlled the lunar spacecraft, mission operations, and crew training. Strongly oriented toward engineering and operations, MSC neither had, nor felt a need for, its own program of basic scientific research. It relied mainly on other projects for the data its engineers required to design their spacecraft. As noted earlier, both Ranger and Surveyor were pressured to supply these requirements, to the considerable resentment of some project scientists.

Homer Newell, among others, felt that manned space flight offered many opportunities to advance space science and worked hard to foster a receptive attitude toward science at MSC. His efforts met with only limited success. A few scientific exercises were carried out on Mercury and Gemini missions, but MSC generally gave them limited attention. The scientists who ventured to fly experiments on manned spacecraft found documentation and test requirements far more demanding than in the unmanned programs and schedules more rigidly enforced.[25] Encountering no respect for their projects and no eagerness to accommodate their requirements, many scientists developed a distaste for working with MSC. Engineers generally returned the scientists' feelings,

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[22] OSSA, "Apollo Lunar Science Program: Report of Planning Teams," part I, Summary (Dec. 1964).

[23] *Space Research: Directions for the Future*, National Academy of Sciences—National Research Council Publication 1403 (Washington, 1966), pp. 21-22.

[24] *NASA 1965 Summer Conference on Lunar Exploration and Science*, NASA SP-88 (Washington, 1965), p. 3.

[25] Newell, *Beyond the Atmosphere*, p. 292.

with interest—with the result that MSC acquired a reputation for hostility toward science.

That reputation was not entirely deserved. MSC's top managers, and most of its rank-and-file engineers, recognized that eventually science would have its day on Apollo. As plans for lunar science matured, Headquarters increasingly urged MSC to provide the support required by experimenters, and transferred responsibility for the lunar surface experiments to Houston. In late 1965, MSC established a Science and Applications Directorate, organizationally on the same level as Engineering and Development, to manage the center's scientific activities.[26] Thenceforth, lunar scientists dealt directly with MSC, not through OSSA, as had been the practice.

MSC's first Director of Science and Applications, Wilmot N. Hess, soon moved to improve relations with the scientific community. In the summer of 1967, he convened a group of lunar scientists to make detailed plans for lunar exploration missions, set priorities for experiments, and recommend development of major hardware items to support extensive lunar exploration. Detailed mission planning proved impossible, because the necessary engineering data was lacking, but Hess did establish the means to provide continuing scientific input to Apollo. Hess set up a Group for Lunar Exploration Planning, a committee of scientists that would meet periodically with MSC operations planners to fashion the best scientific missions possible.[27]

Creation of the Science and Application Directorate gave science a foothold at MSC, but its growth was slow. Hess found that his directorate was tolerated, but not encouraged, by the center generally, and recruitment of research scientists was hampered by budget restrictions.[28] Within a few years, however, lunar and planetary science became an important function at MSC.

Integrating Science into Apollo Operations

Scientists understood that on the earliest missions their interests were not paramount. As soon as the first landing was made, however, they expected more consideration: landing sites chosen for their scientific interest, additional scientific payload, longer stays on the Moon, and a professional scientist assigned to a crew. On the first three matters manned space flight officials yielded as much as they reasonably could, as soon as they could; on the last, they yielded slowly and with considerable reluctance.

Choosing a landing site for an Apollo mission was a complex process, in which many considerations—celestial mechanics, operational limitations, the availability of high-resolution photographs of the lunar surface, and the scientific accomplishments of prior missions—had to be balanced.[29] In 1965, an Apollo Site Selection Board was

[26] Robert R. Gilruth to George E. Mueller, "Change in the basic MSC organization," 4 Apr. 1966; George M. Low to multiple addressees, "Pending MSC Organizational Change," 17 Nov. 1966.

[27] *1967 Summer Study of Lunar Science and Exploration*, NASA SP-157 (Washington, 1967), p. 4.

[28] Wilmot N. Hess, interview with Robert Merrifield, 7 Nov. 1968, transcript in JSC History Office files.

established in OMSF to weigh the operational and scientific factors and choose primary and alternate sites for each flight.[30] In 1967, the Group for Lunar Exploration Planning set up a site selection sub-group to provide the Board with a scientific consensus on the relative desirability of candidate landing sites.

Lacking flight experience and information that would become available only later, MSC's mission planners tended to be conservative in working out details of the early missions. For the first landings they intended to use a "free-return" trajectory, which required somewhat more fuel, but which would return the spacecraft to Earth if its main propulsion engine (for which there was no backup) should fail. This, plus operational limitations imposed by the Earth-based navigation system, defined a landing zone about 150 km wide, extending 1,400 km along the Moon's equator. High-resolution photographs, taken by five Lunar Orbiter spacecraft in 1966-1967, provided sufficient detail for evaluating specific sites within that zone.[31]

Two lunar-orbiting missions (*Apollo 8* and *10*) gave flight controllers a better idea of what they could expect from their systems, and *Apollo 11* made a safe landing on the first try—although, because of last-minute maneuvering to avoid surface obstructions, the lunar module came down with only 45 seconds' worth of fuel remaining.[32]

The primary task accomplished, MSC turned its attention to refining operational procedures, so that scientifically interesting sites could be explored. Furthermore, since the astronauts could cover only about 1,500 meters on foot, it was necessary to land as close as possible to a preselected spot. For the second mission, techniques for separating the lunar module from the command module, and for changes in attitude in lunar orbit, were modified to reduce the random errors that reduced the accuracy of landing. Determination of the lunar module's position and velocity was deferred until just before descent began, and last-minute corrections were sent to the module's guidance computer during descent. Some unavoidable errors remained, but the refinements in techniques enabled *Apollo 12* to land within half a kilometer of its preselected landing site.[33] By contract, *Apollo 11* had missed its target by nearly 6 km.

Equally, or more, important to the scientists was the ability to land anywhere within a wider area on the visible face of the Moon. In June 1969, the Group for Lunar Exploration Planning compiled a list of 21 geologically interesting sites, some as far as 41 degrees from the lunar equator.[34] This list, modified as the project progressed, pro-

[29] Ted H. Skopinski to Chief, Systems Integration Div. (MSC), "Selection of lunar landing site for the early Apollo lunar missions," 21 Mar. 1962; J. O. Cappellari, Jr., ed., "Where on the Moon? An Apollo Systems Engineering Problem," *The Bell System Technical Journal* 51(5) (1972): 955-1127.

[30] Mueller to multiple addressees, "Establishment of Apollo Site Selection Board," NASA Mgmt. Inst. 1152.20, 6 Aug. 1965.

[31] Cappellari, "Where on the Moon? . . ."

[32] MSC, "Apollo 11 Mission Report," MSC-00171 (Nov. 1969), p. 9-24.

[33] MSC, "Apollo 12 Mission Report," MSC-01855 (Mar. 1970), p. 4-25; "Apollo 11 Mission Report," p. 5-25.

[34] "Minutes of the Apollo Site Selection Board Meeting on June 3, 1969."

vided the basis for tradeoffs between mission planners and scientists. Several sites on the list appeared too rough for a safe landing; many others were in regions where Lunar Orbiter photographs were inadequate to certify the site as safe. Landings outside the "Apollo zone" required carrying maneuvering fuel at the expense of scientific payload. Sites at extreme latitudes could be reached only once or twice a year, because of the limits of the Saturn V's payload capacity. Some of the limits imposed (somewhat arbitrarily) on early missions could be relaxed as experience accumulated; but this only led flight planners to the ultimate limits of the Saturn/Apollo vehicles.

Over the course of the project, operations, rather than science, usually prevailed in the choice of landing sites, since the safety of the astronauts was the consideration from which most operational rules arose. While flight planners never agreed to a site that compromised safety, they did go to some lengths to accommodate the scientists' wishes as they gained experience with their equipment and procedures. A mission rule forbidding night launches was waived for the last mission (*Apollo 17*); a significant increase in payload could be gained by a night launch. And when initial calculation showed the terrain to be unacceptable at the site most favored by the scientists for *Apollo 17*, the scientific value of the site was emphasized to flight dynamics officers, who reconsidered their calculations in light of experience on *Apollo 15*, decided their initial numbers had been too conservative, and pronounced the site acceptable.[35]

Extending the Missions

The key to increasing the scientific productivity of the Apollo missions was increasing the payload landed on the Moon. Both the 1965 and 1967 summer studies stressed the importance of increased surface mobility, longer times on the lunar surface, and additional equipment. From 1962 to about 1968, Apollo plans contemplated a lunar logistic-support system, consisting of a second (unmanned) lunar module modified as a supply vehicle and landed at the mission site by a second Saturn V. This spacecraft was to carry additional scientific equipment, plus supplies to support missions as long as 14 days.[36] By early 1968, however, the plan had disappeared from OMSF's presentations to Congress, and attention was focused on modifying the manned lunar module to support two astronauts for as long as 3 days on the lunar surface.[37] Before the first landing was accomplished, the lunar module contractor was directed to begin modifying subsequent spacecraft to accommodate the added weight of consumables required by the longer missions.[38] A contract was also let for a powered surface-traversing vehicle (the lunar rover), which would extend the astronauts' range by tenfold.[39]

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[35] John R. Sevier, interview with the author, 24 Apr. 1986.

[36] U.S., Congress, House, Subcommittee on Manned Space Flight of the Committee on Science and Astronautics, *1966 NASA Authorization*, hearings on H.R. 3730, 89th Cong., 1st sess., part 2, p. 141.

[37] Idem, *1969 NASA Authorization*, hearings on H.R. 15086, 90th Cong., 2nd sess., part 2, p. 29.

[38] MSC to Grumman Aircraft Engineering Co., contract change authorization no. 2333, "LM-10 and subsequent modification program," 9 June 1969.

Until the extended lunar module became available, flight planners extended the time on the Moon by trimming the generous weight margins that had been considered necessary for the first landing. Much was done with those margins: *Apollo 12* stayed 32-1/2 hours on the Moon, compared to *11*'s 21-1/2, and the crew spent 7 hours 45 minutes in two excursions on the surface—more than three times as long as the first explorers had spent in their single trip outside the spacecraft.

To lift the extra payload planned for the extended lunar missions, changes in the Saturn V and in launch procedures were also required. Payload increases were made possible by readjusting the first-stage engines to a higher thrust level and optimizing propellant loading, to leave less unburned fuel when the engines cut off. Reducing the altitude of the Earth parking orbit and optimizing the launch azimuth added more, with the result that on the last three missions the spacecraft weighed, at launch, some 2,900 kg more than on the first.[40]

All the improvements came together for the first time in late July 1971, when *Apollo 15* departed Kennedy Space Center bound for a spot between *Hadley Rille* and the *Apennine front*, 800 km north of the lunar equator. Besides the new lunar roving vehicle, *Apollo 15* carried a lunar module capable of staying 3 days and a service module fitted with several remote sensors, a mapping camera, and a scientific satellite, to be deployed in lunar orbit to measure particles and fields. *Apollo 15* was the first of three extraordinarily productive missions that extended the Apollo hardware virtually to its limits.

Crew Selection

Of all the questions that divided scientists and NASA engineers, that of choosing crews for the lunar mission was the most difficult to settle objectively. Soon after the decision was made to send men to the Moon, scientists went on record insisting that an experienced scientist be included in every crew that landed on the Moon. Only a scientist, they said, could make useful observations and collect significant samples, especially in the short time the first explorers would be on the Moon. The 1962 summer study reaffirmed this conviction, and more: it recommended that NASA establish a graduate college for astronauts, so that scientist-astronauts could maintain their research proficiency and pilot-astronauts could be well schooled in disciplines appropriate to space science.[41]

The Manned Spacecraft Center, however, had the responsibility for selecting and training astronauts and assigning crews to missions, and MSC managers regarded Apollo as an experimental project, for which experienced test pilots were best suited.[42] The first two groups (16 astronauts), chosen in 1959 and 1962, were all test pilots. The third (14

[39] Mueller to NASA Administrator, "Manned Space Flight Weekly Report," 3 Nov. 1969.

[40] JSC, "Apollo Program Summary Report," JSC-09423 (Apr. 1975), pp. C-3, C-4.

[41] *A Review of Space Research*, p. 11-16.

[42] C. C. Kraft, Jr., to A. M. Chop, "Article on Astronaut Selection in November 7 Issue of Time Magazine," 8 Nov. 1962.

astronauts), selected in 1963, included only two test pilots, but all 14 were jet pilots with at least 1,000 hours of flying time. Two men with scientific credentials, as well as flying experience, came into the program with the third group.[43]

Since it seemed likely that the first lunar explorers, at least, would come from these groups, MSC incorporated a basic course in geology into the astronaut training program. Structured at first much like an elementary college course, the geology training evolved into a program stressing field observation of landforms, accurate description of details, and careful sampling.[44] Some of the astronauts had a natural knack for field geology; others were much less interested. In any case, the field trips—to Hawaii, Iceland, West Germany, and Alaska, as well as the western U.S.—were enjoyable diversions from the training routine.[45]

In early 1964, NASA Headquarters, anticipating post-Apollo manned programs in which science would play a larger role, announced that the next group of astronaut trainees would be chosen for their scientific qualifications. At NASA's request, the National Academy of Sciences established qualifications and conducted the preliminary screening of some 400 applications, sending 16 names to MSC for the final selection. In mid-1965, six candidates were chosen: one geologist, two physicians (one of whom resigned before beginning training), and three physicists. Two were qualified jet pilots; the others were sent to Air Force flight school for a year.[46]

Astronaut status created problems for scientists. A fundamental tenet of the community that had secured their admittance to the astronaut corps was that scientists must have time to pursue research. But as astronauts they were expected to participate in a myriad of time-consuming engineering and operational activities—contributions necessary to the flight program, but not beneficial to their scientific careers. Harrison H. ("Jack") Schmitt, a Ph.D. geologist, found an appropriate niche in the geology training program, especially in the later stages of Apollo, and he had an important role in coordinating science and flight operations. The others, whose fields were not so directly applicable to lunar exploration, gravitated to the science-oriented Apollo Applications Program, which was taking shape between 1965 and 1969.[47]

When it came to flight assignments, however, the scientist-astronauts were clearly second-class citizens. Donald K. ("Deke") Slayton, director of flight crew operations at MSC and the man most responsible for selecting flight crews, never disclosed the basis for his choices; but throughout Gemini, and well into Apollo, spacecraft were manned

[43] U.S., Congress, House, Committee on Science and Technology, *Astronauts and Cosmonauts: Biographical and Statistical Data [Revised May 31, 1978]*, report prepared by the Congressional Research Service, Library of Congress, July 1978.

[44] Elbert A. King, Jr., interview with Loyd S. Swenson, Jr., 29 May 1971, tape in JSC History Office files; Harrison H. Schmitt, interview with the author, 30 May 1984.

[45] King interview.

[46] Courtney G. Brooks, James M. Grimwood, and Loyd S. Swenson, Jr., *Chariots for Apollo*, NASA SP-4205 (Washington, 1979), p. 180.

[47] Joseph P. Kerwin, Jr., interview with the author, 29 May 1985.

only by test pilots. Seniority in the astronaut corps appeared to be the dominant factor—until scientist-astronauts achieved seniority. Slayton repeatedly justified his preference for test pilots on the basis that landing on the Moon was a difficult and dangerous business, for which a test pilot's experience was the best preparation. He was unwilling to stake the success of a lunar landing on the ability of a scientist, no matter how well trained he might be in flying a lunar module, to react appropriately to an emergency that might call for an instinctive—and correct—reaction.[48]

Prime and backup crews for the first four Apollo missions were named between January and August 1969, none of them including a scientist-astronaut. Scientists took this as one of many instances of MSC's hostility toward science. In the autumn following the first lunar landing, their frustration with NASA's neglect of science in Apollo came to a head. A flood of criticism from scientists appeared in the public press, mostly assertions to the effect that NASA's managers did not appreciate the needs or the importance of science.[49] Whether in response to these criticisms, or merely for the reason that the time had come, in March 1970, Slayton named the only geologist-astronaut, Jack Schmitt, to the backup crew for *Apollo 15*.[50] In the normal scheme of crew rotation, Schmitt could expect to be lunar module pilot on *Apollo 18*, the last mission but one as the schedule then stood.

Schmitt's reservation on a Moon-bound spacecraft was by no means confirmed, however. In January 1969, a new national administration took office, one which had no strong commitment to space, but which had been elected with a commitment to reduce government spending. NASA's budgets began to drop. The space agency was forced to make hard choices between current programs and future development. In January 1970, one lunar mission, *Apollo 20*, was canceled; nine months later, two more.[51] The crew that would have manned *Apollo 18*, including Jack Schmitt, was left without a mission. After long discussions, Homer Newell and manned space flight officials agreed that, provided Schmitt completed his training satisfactorily, he would be assigned to the crew of *Apollo 17*, the last lunar mission.[52] In August 1971, Slayton announced that Eugene A. Cernan, Ronald E. Evans, and Harrison H. Schmitt would man *Apollo 17*. Test pilot Joe H. Engle had trained with Cernan and Evans as the backup crew for *Apollo 14*; but Slayton never adopted a firm rule to promote backup crews as a unit to a flight crew, although he favored it as a general policy. In this case, circumstances forced Engle off

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[48] Paul Recer, "They Feud Over Moon Flights," *Miami Herald*, 18 Aug. 1969; B. J. Richey, "Lunar Landing Team Are Unlikely To Include Scientists Until 1971," *St. Louis Globe-Democrat*, 18 Aug. 1969.

[49] Marti Mueller, "Trouble at NASA: Space Scientists Resign," *Science* 165 (1969): 776-779; John Noble Wilford, "Moon Scientists Seek Place in the Sun," *New York Times*, 10 Aug. 1969.

[50] NASA Release 70-46, "Apollo 15 Crew Selected," 26 Mar. 1970.

[51] "Apollo Missions Extended to '74," *New York Times*, 5 Jan. 1970; NASA, "FY 1971 Interim Operating Plan News Conference," 1 Sept. 1970, transcript; Thomas O'Toole, "2 Moon Landings Canceled by NASA," *Washington Post*, 3 Sept. 1970.

[52] Dale D. Myers to Charles H. Townes, 1 Mar. 1971.

the last mission, and he was assigned to the Shuttle Orbiter program, which by then had emerged as the manned space flight project of the future.[53]

So, on 11 December 1972, the first scientist set foot on the Moon near the southeastern rim of *Mare Serenetatis*, where during the next three days he spent 22 hours exploring the valley called Taurus-Littrow.[54] How much his presence enhanced the scientific results of the mission is difficult to assess. Certainly he was able to give better geologic descriptions of what he saw, and no doubt his experience in field geology contributed to a better selection and documentation of samples than earlier missions had achieved. By the time that happened, however, the perceived value of having a geologist on the Moon was considerably less than it had been before the landings began (see below).

Summary and Conclusions

The scientific accomplishments of Apollo were truly unique, but they were not achieved without difficulty. Both engineers and scientists believed their objectives to be paramount, but in the early stages the priority of the lunar landing as such gave engineers the upper hand. Concern for the safety of the astronauts made the engineers cautious in their choice of landing sites, trajectories, and margins to be allowed for contingencies. Their justifiable conservatism in approaching a completely unknown situation led to an emphasis on safety at the cost of scientific payload and time on the Moon. Thus, the first set of instruments, left by *Apollo 11*, was a simplified package weighing less, and requiring less deployment time, than the larger, more productive package originally planned (and carried on subsequent missions). The first men to set foot on the Moon spent only 2-1/2 hours outside their spacecraft, with flight controllers constantly monitoring their life-support systems and holding them close to the preplanned sequence of operations.

Scientists conceded the unique nature of the first lunar landing, but after it succeeded they chafed under the restrictions imposed by the engineers. When it became apparent that the second mission would not be much different from the first, a flood of criticism from scientists and their advocates in the press was unleashed on NASA, with accusations that the space agency (and particularly MSC) neither understood, nor sympathized with, the objectives of science.[55] Exactly what that meant was not clear, but it appears that the scientists believed it was time for the engineers to relinquish control of the project to scientists—or at least to give scientists the authority to make the key decisions concerning the remaining missions.[56] If that was indeed what they wanted, it

[53] NASA Release 71-149, "Apollo 17 Crew Named," 13 Aug. 1971; MSC, "Apollo 17 Crew Press Conference," 19 Aug. 1971, transcript.

[54] Harrison H. Schmitt, "Apollo 17 Report on the Valley of Taurus-Littrow," *Science* 182 (1973): 681-690; *Apollo 17 Preliminary Science Report*, NASA SP-330 (Washington, 1973), pp. 5-1 to 5-21.

[55] "Scientists vs. NASA," unsigned editorial in the *New York Times*, 12 Aug. 1969.

was a forlorn hope; as long as MSC bore the responsibility for mission success and crew safety, it would not yield the authority to decide where the spacecraft would land and what the crews would do on the Moon.

Flight planners were willing, however, to design the remaining flights to give lunar science the maximum possible support. Immediately after *Apollo 11*, Headquarters gave the order to proceed with long-term improvements. For the short term, flight planners used what they had learned on *Apollo 11* to improve the scientific productivity of the interim missions as much as possible, by fine-tuning all phases of mission operations to increase the landed payload. And as soon as precision landings could be made, they assigned the landing site having the highest scientific priority (the Fra Mauro Formation) to the next mission.

Scientists welcomed all these improvements, but they were not enough for some critics, who felt that operational restrictions still dominated, and that science lacked the influence it deserved. In February 1970, MSC director Robert R. Gilruth brought most of his principal lieutenants and the most prestigious lunar scientists together to work out their differences. The result was the formation of a Science Working Group composed of scientists and MSC flight planners, who would work closely together in planning every detail of the extended lunar missions, starting with *Apollo 15*.[57] The objective was to produce the most science possible within those operational limits that were considered absolutely inviolable.

Many significant changes were incorporated into the last three Apollo missions. Landing sites were chosen with a view to maximizing the utility of seismic instruments, on condition that the scientifically interesting site was operationally acceptable. Perhaps most gratifying to scientists, considerable flexibility was introduced into lunar surface operations. Scientists were on hand in the Mission Control Center, assessing results as they came in, and changing the plans for later surface excursions in light of what was accomplished on earlier ones. The addition of color television to the lunar roving vehicle virtually enabled ground-based scientists to look over the astronauts' shoulders as they worked.

It was well that such close cooperation was achieved, for in September 1970, two of the nine remaining missions were canceled. Scientists protested, but to no avail. Apollo's early success had been its downfall: the mass-communications media, and much of the viewing public, quickly lost their fascination with lunar exploration. The Nixon administration took office in January 1969, more concerned with foreign affairs than space, and committed to reduce government spending. NASA soon found its budgets too small to allow continuing the lunar landing, while laying foundations for future programs.

The scientific dividend of Apollo was enormous, and it seems unlikely that the three canceled missions would have added much to it, had they been flown. So little was definitely known about the Moon before Apollo, that the first samples baffled as much as they enlightened. As more data and material was returned, the picture became some-

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[56] Fred L. Whipple to George E. Mueller, 1 Aug. 1969; Alex J. Dessler, "Discontent of Space-Science Community," MS. for journal article, 30 October 1969, copy in JSC History Office files.

[57] Sevier interview.

what clearer. Still, in the three and a half years of Apollo, it would have been difficult to pick three additional landing sites that could have been expected to clarify the scientific understanding of the Moon further. The canceled missions would have given six more astronauts the chance to walk on the Moon and they would have brought back several hundred more kilograms of Moon rocks and soil. What lunar science needed in 1973, however, was time to assimilate the results Apollo had already produced. Only then could further lunar exploration be planned intelligently.