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The Apollo Program: Was It Worth It?*

By Paul D. Lowman, Jr.†

Six years ago this summer the spacecraft Eagle landed on the moon, and men from earth walked on the soil of another world for the first time in history. The Apollo program thus culminated in what generally is agreed to be the greatest technological feat ever accomplished. But even today the program is controversial. Was it worth what it cost? Or could the money, skill, and effort have been used in better ways? And why bother discussing it now, since the program is long since over?

To answer the last question first: the study of history, to which Apollo now belongs, is always worthwhile, both for itself and as a guide to the future. But in addition, the value of science in general is questioned widely today, and study of the Apollo program may help answer the broader questions of how much technological progress we really want, and how rapid should be such progress as we do want. Finally, the American people will be called upon again and again to decide, through their representatives, complex scientific and technological issues comparable to the decision to go to the moon. Should we mine oil shale on the Colorado Plateau? Build breeder reactors? Control the weather? A look back at Apollo may help clarify the decision-making process, and provide guidance for the future.

I was one of the many thousands who took part in the manned space flight programs Mercury, Gemini, and Apollo, and I naturally feel that they were worth what they cost. My purpose here is to justify this view by summarizing the main results, direct and indirect, of the Apollo program. This article can be considered the case for the affirmative, but I also will discuss briefly some of the arguments against Apollo, which center chiefly around its cost and the question of whether unmanned spacecraft could have done the job as well (and more cheaply).

Let me begin by establishing a few fundamentals. What *was* the Apollo program? And how much *did* it cost?

The Apollo program itself was a research and development effort that

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began (effectively)[1] in May 1961, when President John F. Kennedy proposed to Congress that the United States undertake to land a man on the moon "in this decade." At that time, the United States had accomplished one space flight—Alan Shepard's suborbital Mercury flight—and since the Mercury program was a limited one, an interim series of spacecraft was proposed. The Gemini program, as this interim effort was named, was solely preparation for Apollo, to develop techniques of orbital rendezvous, extravehicular activity, and the like. For the purposes of this discussion, therefore, I shall consider Gemini part of Apollo.

The Apollo program eventually accomplished two earth-orbital missions (7 and 9), two circumlunar non-landing missions (8 and 10), one aborted mission that went around the moon (13), and six lunar landings (11, 12, 14, 15, 16, and 17). The program returned some 385 kilograms (850 pounds) of rock and soil, 33,000 lunar photos, and 20,000 reels of magnetic tape data.[2] In addition, the lunar landing missions emplaced five nuclear-powered geophysical stations, all of which are still transmitting some data at this writing. The earth-orbital Apollo missions carried out a number of scientific experiments, and returned about 800 terrain photographs of the earth.[3] The Gemini program, though aimed primarily at developing various space techniques, also carried out several dozen scientific and medical experiments that produced thousands of photographs and many other data.

What did these programs cost? In round numbers, the total cost for the Apollo program, through the last lunar landing (Apollo 17), was $25 billion, and for Gemini, $1.3 billion. These figures include all research, development, and construction of facilities, as well as the missions themselves, over the period 1961 through 1972. For comparison, the total federal budget for fiscal year 1972, when the Apollo program ended, was $265.7 billion; the FY 1972 budget for the Department of Health, Education, and Welfare alone was $71.7 billion.[4] The total NASA appropriation for all purposes (including Apollo and Gemini) for 14 years, 1959-1972, was $46.8 billion. The argument for the affirmative begins here, for very few people realize how little the American space program has cost in relation to other expenditures.

Before answering the question of whether Apollo was worth its cost, I should point out that it is hard to single out the direct results of the Apollo and Gemini programs from results of the United States civilian space effort in general. However, I shall try to do this, and will, therefore, omit topics such as weather and communications satellites, whose value is conceded even by critics of manned space flight. A good general discussion of the results of space research has been presented by C.P. Boyle.[5] One final point: full application of scientific research generally takes years or decades after the research itself has been completed. For example, the invention of the laser in 1960 was the ultimate outcome of a paper on stimulated emission of radiation published by Einstein in 1917.[6] Therefore, any discussion of the results of the Apollo program must be considered at this time only a progress report, to be continued—next century.

A TEST OF DEMOCRACY

The phrase "race to the moon," often used by critics of Apollo, is misleading; the successful landing of Apollo 11 in 1969 was a striking demonstration of the effectiveness of the democratic form of government in responding to challenge. To fully understand this statement, we must go back to 1957. The launching of Sputnik 1, the world's first artificial satellite, on Oct. 4, 1957, by the Soviet Union sent a shock wave of uncertainty, even of fear, through the United States and, indeed, through the western world. Sputnik 1 was not only first, but weighed nearly nine times as much as the yet-unlaunched American Vanguard satellite; and it was followed just a month later by Sputnik 2, weighing over 500 kilograms (1100 pounds), six times as much as Sputnik 1. For several years after these events, Americans questioned the value of their educational system, the strength of their armed forces, and even the fundamental effectiveness of the democratic form of government.

The complementary reaction in the Soviet Union was an "orgy of patriotic pride and self-congratulation,"[7] quite understandably. One can hardly blame the Russian people for filling Red Square to cheer their space achievements. But there was a dark side to this reaction: a massive surge of confidence in the power and efficiency of Marxism. Nikita Kruschev displayed a new aggressiveness in the months after Sputnik 1, freely warning the western nations of the danger from Soviet missiles. Andrei Gromyko, on Dec. 21, 1957, addressed the Supreme Soviet thus: "The situation in the world today is different from what it was even a few months ago. The Soviet earth satellites have improved the political climate on our planet."[8]

It is quite clear that space exploration in the late 1950s was viewed universally as a contest between two fundamentally different forms of government. The next major move in this contest was President Kennedy's proposal in 1961 to land an American on the moon by the end of the decade.[9] This response to the challenge of Sputnik was a daring one, in the eyes of many a rash one. But a little more than nine years later, the United States had won the space contest, not just decisively, but overwhelmingly, *and* had done it while carrying out programs of social reform, urban renewal, poverty alleviation, and improved education, to say nothing of waging a major war.

What was the Russian reaction to this American triumph? Perhaps the most striking evidence of how Apollo 11 affected Russian thinking can be found in an open letter to the heads of the Soviet government sent in 1970 by three leading liberals, A.D. Sakharov, V.F. Turchin, and R.A. Medvedev.[10] The letter is a catalog of Russian shortcomings and failures, and states in the second paragraph: "At the end of the 1950s our country was the first to launch a sputnik and it sent a man into space. At the end of the 1960s we lost our lead and the first men to land on the moon were Americans . . ." Sakharov and his colleagues then proposed a broad program of "democratization," including greater freedom of information, easing of restrictions on expression of opinion, amnesty for political prisoners, and multi-candidate elections. Now the importance of Apollo in stimulating this remarkable and courageous letter should not be exaggerated. Sakharov and other Russian liberals long have held such views; furthermore, they reasserted in the letter their faith in "socialism." But they nevertheless found it worthwhile to cite prominently the American lunar landing as a symbol of the superiority of democratic institutions.

An important aspect of the American victory in the race to the moon should at least be mentioned, if only speculatively. The Apollo program was a non-military one, but it nevertheless involved developments in many technological areas that also are crucial to national defense: rocket propulsion, inertial guidance, computer utilization, electronics, radar, remote sensing, advanced materials, and others. The success of Apollo thus provided, in addition to the test of democracy just discussed, a demonstration of the inherent superiority of American technology. It seems safe to suggest that this demonstration is a real contribution to prevention of a global thermonuclear war; no potential aggressor could plan a surprise attack on the United States without taking into account the military strength implied by it.

IMPROVEMENT OF INTERNATIONAL RELATIONS

Although space exploration obviously has not been completely effective in providing, as once hoped, a substitute for war, it certainly has played some part in improving international understanding and cooperation. The Apollo 11 landing on the moon itself had tremendous psychological impact on humanity, partly because nearly 1½ billion people were able to watch it by satellite-relayed television. It is certain that never before had so many human minds been focussed simultaneously on one subject. Surely this shared experience, this step toward world consciousness, can be considered an achievement, if a temporary one, of the Apollo program. However, one can point to more specific contributions to better international relations.

To begin with, the Apollo program directly involved many countries besides the United States. The NASA tracking network, for example, has stations in all parts of the world, partly staffed by citizens of the countries involved. "We came in peace for all mankind," the statement on the metal plaque attached to the Apollo 11 lunar module, must have real meaning for these people. Apollo 13 provided a nearly tragic example of the unifying effect of space exploration; when the service module exploded partway to the moon, offers of help poured in from around the world. Of particular interest was that of Russian aid in recovering the spacecraft on landing. Fortunately, it was not necessary to take advantage of these generous offers, but they will not be forgotten.

The samples and data returned from the moon have been shared with many nations, and not just as ceremonial gifts. Hundreds of scientists from other countries have received rock and soil samples for study. It should be pointed out here that such international distribution is possible because of the great amount of material brought back from the moon (850 pounds). The two unmanned sample return missions flown by the Soviet Union, in contrast, have returned only about five ounces.

Perhaps the outstanding example of international cooperation stimulated by Apollo is the Apollo-Soyuz Test Project, undertaken in July 1975. Invitations for such cooperation were issued by the United States as early as 1961, but generally met with little Russian response. Apart from the fact that the ASTP uses an Apollo spacecraft and related technology, it seems safe to suggest that the success of the lunar landing played a major role in persuading the Soviet Union to take part in joint efforts.

Looking backward, it is obvious that the Apollo program has not created a new world of peace and understanding. But it has at least thrown a few bridges across international chasms whose existence contributes to the problems of the old world. Furthermore, Apollo suggests what a long-range, ambitious space program could eventually do to unite the human species.

NEW KNOWLEDGE OF THE UNIVERSE

To a scientist, the most conspicuous results of the Apollo program are the data and samples returned from the moon; these are slowly being translated into an immense body of new knowledge about the universe. And please note that I say "universe," not "moon"; the reasons for this choice of words will soon become apparent.

To summarize the scientific findings of Apollo, even briefly, is impossible here.[11] The *preliminary* science report for *one* mission (Apollo 17) weighs 3½ pounds, and several thousand individual papers have been published on various aspects of the Apollo results. Consequently, I will only mention a few of the major areas in which the most progress has been made.

Before doing this, it may be helpful to remind the reader that the Apollo lunar landing missions actually were complex expeditions; the astronauts did far more than put up a flag and collect rocks. For example, on a reasonably typical mission, Apollo 16, the astronauts accomplished the following things on the moon during the nearly three days they spent on the surface: emplaced geophysical instruments, made a local seismic survey, took magnetic field readings, took ultraviolet photos of the earth, the Milky Way, the Magellanic Clouds, and other celestial objects, made a soil survey, collected 210 pounds of rocks and soil, took hundreds of photographs, and did a number of other experiments. But these were only the *surface* activities; the command module in lunar orbit carried out X-ray and gamma ray surveys of the moon, made radar measurements, took systematic panoramic and metric photographs, and launched an 84-pound satellite into orbit around the moon, in addition to other scientific and biological experiments.

It will be obvious that even one Apollo mission such as this produced more knowledge about the moon than all previous earth-based studies together, and of course has told us much about the moon impossible to determine at all from the earth. (The September 1973 *National Geographic* summarizes some of this knowledge.) We now know the moon's age, its gross structure, its internal temperature, and a good bit about its composition. Many questions remain (many new ones have in fact been raised), but it is already possible to reconstruct the moon's geologic history in surprisingly great detail.[12] The moon originated about 4.6 billion years ago by some rapid, high-temperature process. It was partially melted early in its history, perhaps 4.4 billion years ago, and formed a global igneous crust composed chiefly of aluminum-rich igneous rocks. It was being heavily bombarded by objects of various sizes, forming impact craters. This bombardment culminated about four billion years ago when several especially large impacts formed the circular mare basins. For the next billion years or so, great eruptions of basaltic lava occurred, covering much of the earthward face of the moon. This was essentially the end of the moon's geologic evolution, except for primarily external later events such as further impact cratering and erosion processes.

Apart from its inherent interest, the moon's evolution is of great importance for the study of planets in general, including the earth. The Mariner 10 photographs of Mercury showed it to be in most respects similar to the moon, implying that despite its close, and so far unexplained, relation to the earth, the moon is a normal small silicate planet. But because the moon preserves a much better record of its early history than does the more active earth, we can, with caution, infer something about the evolution of the earth. Several geologists studying terrestrial Precambrian geology have found similarities between lunar and terrestrial features whose origin is not understood. The most important of these features is the very continental crust, for which there is so far no really convincing theory of origin. I have proposed[13] a somewhat radical theory, based on lunar geology, that the earth's continents have not grown through geologic time by the lateral accretion of mountain belts, as widely believed, but are, instead, the greatly-altered remnants of a primitive global crust analogous to the lunar highlands. Although controversial, this proposal at least illustrates a possible approach to the most obscure part of our planet's history, the first billion years.

It should be mentioned here that the Apollo program and its direct predecessor, the Gemini program, have produced a substantial amount of new knowledge about the earth directly, by means of orbital photography.[14] Most Gemini and Apollo missions carried terrain photography experiments whose objective was to obtain color or multispectral photos of geologic or oceanographic features of scientific interest, such as the African rift valleys and the Himalayas. Roughly 2000 pictures were taken, and they have been used widely by geologists, geographers, oceanographers, and teachers. Geologic maps have been revised substantially in some areas, and many previously unknown structures discovered. The Gemini and Apollo photographs greatly stimulated interest in orbital remote sensing, and contributed to the development of the Earth Resources Technology Satellites LANDSAT-1 and LANDSAT-2, which now return imagery from earth orbit on a regular though still experimental basis.

Returning to the Apollo lunar missions, I must at least mention some of the other scientific results. The soil samples collected by the astronauts proved to contain a small but identifiable amount of meteoritic material. Some of it resembles well-known meteorites, but several varieties are chemically quite distinct from those that have been collected on earth. The moon's soil, being exposed directly to the solar wind and to cosmic rays, has been found to be an excellent radiation counter, preserving a record of cosmic and solar radiation over the past several billion years. Hydrogen and helium from the sun have been trapped in the lunar soil, making it possible to study the fossil solar wind. The present-day solar wind has been studied directly, by analyzing aluminum foil sheets exposed on the moon's surface by the astronauts; this simple but ingenious experiment has thus made it possible to, in effect, sample the sun. Several biological and medical experiments were flown on Apollo missions. Among them was the Biostack Experiment,[15] in which a variety of seeds and organisms, sandwiched between layers of radiation-recording film, were carried in the command module and exposed to cosmic rays beyond the earth's magnetic field. This experiment is expected to yield new knowledge about the effects of radiation on cells.

In summary, it is clear that the Apollo program has produced a rich harvest of knowledge in geology, astronomy, physics, biology, and other scientific fields, and has taught us much about the evolution of our own planet, the earth. Now let's look at still other results.

STIMULUS TO TECHNOLOGY

The Apollo program has been labeled, in space-age jargon, a technological "forcing function."[16] In plain English, this means that Apollo has stimulated progress in applied science, or technology. And despite the misgivings of some critics, it has had just this effect, as a few examples will illustrate.

It should first be pointed out, in order not to overlook the obvious, that the Apollo program has, above all, given us mastery of manned space flight technology. We have sent men six times on what were essentially short interplanetary expeditions. These men have lived on the moon for as long as three days, eating, sleeping, working, and driving many miles over the cratered terrain in an electric car. After the Apollo program, its spacecraft and launch vehicles were used for a 100-ton space station, Skylab, which was operated successfully for several months. To put it concisely, we are now at home in space.

Apart from space technology itself, the Apollo program had great impact in other fields. One of the most important of these is the development of computer technology. The Apollo missions depended on the ability to perform massive real-time calculations of orbits and trajectories, and the program thus triggered unusually rapid progress both in computer hardware and in programming capability. These are major assets in today's competitive world. Let me again quote from the letter by Dr. Sakharov and his colleagues, specifically from the first paragraph: "Comparing our economy with that of the U.S., we see that ours lags not only in quantitative but also—saddest of all—in qualitative aspects. . . .we lag behind in oil drilling . . . hopelessly lag behind in chemistry . . . and infinitely lag behind in computer technology. As for the use of computers in the economy . . . a phenomenon that has deservedly been called the second industrial revolution . . . here the gap is so wide that it is impossible to measure it. We simply live in another epoch."

Turning to other technological developments, we see such widespread effects of the Apollo program although, as in science, only a few highlights can be given. It should be pointed out here that NASA has made a major effort, through its Technology Utilization program, to see that new materials, devices, and computer programs stemming from Apollo and other space projects are fed back into industry. Thousands of technology utilization publications have been issued, and are available to anyone (American or foreign) for a nominal charge. The following discussion is based chiefly on some of these publications.

The deaths of Apollo 1 astronauts Grissom, White, and Chaffee in the tragic fire of Jan. 27, 1967, triggered a massive NASA effort in fireproofing technology. Although obviously oriented toward spacecraft, this effort produced a wide variety of new materials, designs and testing procedures that amount to what Congressman Jerry L. Pettis called "a breakthrough in fireproofing technology" with "profound life-preserving implications."[17] Comparable developments resulting from the manned space program, chiefly Gemini and Apollo, can be cited in medical telemetry. NASA had to learn how to monitor, in real-time, the heart rates and other physiological functions of astronauts in flight (and eventually on the moon), and this requirement stimulated the development of rugged, miniaturized devices for telemetering such data without interfering with the astronauts. Many hospitals now are using such devices. Preventing injuries is of course better than healing them; a highway crash barrier has been developed using a shock-absorption principle first used to cushion astronauts' spacecraft seats. There are scores, even hundreds, of similar direct or nearly direct applications of Apollo hardware. For example, the development of the Saturn launch vehicle has aided the fight against air pollution. How? The Chrysler Corporation was able to modify its auto distributors for more precise ignition timing, to meet the requirements of the Clean Air Act, by testing them with equipment derived from that used to check out the Saturn rockets.

An example of the technological stimulus of the Apollo and Gemini programs can be found in still another field, namely remote sensing (including aerial photography). As I mentioned earlier, the photographs of the earth taken by Gemini and Apollo astronauts greatly stimulated interest in orbital earth surveys, whose potential value (except for meteorology) was virtually unrecognized before 1963. NASA began what was then called a "Natural Resources Program," under the leadership of P.C. Badgley, in that year, whose objective was to develop the technology for earth resources surveys from space. This program involved use of sensing devices such as radiometers, radar, infrared scanners, and of course cameras, all of which were extensively tested from aircraft to see if they were suitable for use in earth orbit, and to study their limitations. These devices have all since been used successfully, either in earth orbit or on Apollo lunar missions. However, the NASA earth resources program also triggered a surge of progress in *aircraft* remote sensing as a by-product of its airborne test flights. Since aerial surveys always will be better than orbital surveys for many purposes, this progress can be considered an indirect result of the Mercury, Gemini, and Apollo programs. We have, in effect, looked back at the earth on our way to the moon.

A WHOLE PLANET

The Man Who Sold the Moon, a 1949 science fiction novel by Robert Heinlein, can even today be read with pleasure. The central figure, D.D. Harriman, in trying to get company funding for a flight to the moon, says: "Don't ask me what we'll make a profit on; I can't itemize the assets—but I can lump them. The assets are a planet—*a whole planet* . . ." (emphasis Heinlein's). Like the mastery of space technology, this result of the Apollo program is so obvious that it's easy to forget. But we have accomplished the first exploration of a planet whose total area is roughly equal to that of North and South America combined; we have quantitatively equaled the discovery of America by Columbus.

But so what? The moon is 240,000 miles away, it has no air, apparently no water, and as we have just seen, its surface is bombarded with unshielded solar and cosmic radiation. These objections are faintly reminiscent of those raised against the purchase of Alaska. In fact, the potential "uses of the moon," to use Arthur Clarke's phrase, are many.[18] Scientifically, the moon as an object of study barely has been touched; we never have sent astronauts to a really big crater, to the polar regions, or to the far side. As a base for scientific observation, the moon has several areas of superiority to earth-orbiting space stations or satellites. The far side, shielded from terrestrial radio interference, is probably the best place in the inner solar system for radio astronomy. Optical astronomy, although done now from earth orbit (with the Orbiting Astronomical Observatory and other satellites), can benefit from the stable foundation and slow rotation time provided by the moon. A variety of physics experiments utilizing the very hard vacuum of the lunar surface can be imagined. Gamma ray and X-ray astronomy can be done from the moon, using the limb as an occulting disk.

Looking further into the future, it is quite conceivable that a self-supporting colony can be established on the moon, paying its way with scientific research, tourism, and specialized manufacturing requiring large volumes of hard vacuum. If substantial water sources can be found—at the moment, a dim prospect—the moon could serve as a rocket launching site, using hydrogen and oxygen for fuel. (The oxygen is already there in abundance, as silicates; what we really need is hydrogen.) Even without a fuel source, rocket launches from the moon using an electric catapault, impractical from the earth because of air resistance, may be practical, since escape velocity from the moon is only about a fifth that of the earth's.

THE INTANGIBLES

The Apollo program has had a number of results that do not fit any of the categories discussed so far; I shall call them the "intangibles." Their very existence perhaps is debatable, and their value depends on who does the evaluation.

Probably the least debatable "intangible" is the great broadening of our scientific horizons, in particular in fields such as geology, geophysics, and planetary studies. Let me give a personal example of this broadening. Several years ago, while at the Jet Propulsion Laboratory for the Mariner 9 mission, I happened to meet several old friends, all geologists on the Mariner TV team, in a Pasadena restaurant. Our careers had been roughly parallel since graduate school at the University of Colorado, theirs with the United States Geological Survey, mine with NASA. We talked geology, as geologists do: about Mars and Mariner, of course; then about Colorado; then California; then the moon. As I left the restaurant, it struck me that we had been talking, from personal experience, about the geology of *three* planets. Our horizons had been widened to a remarkable degree; and in the years since, our profession, geology, similarly has been widened. New geology books, for example, may have individual chapters about the moon, Mars, and Mercury; geological and geophysical meetings generally have dozens of papers on extraterrestrial studies; the very term "geology" is now occasionally replaced with "planetology."[19]

Another "intangible" is typified by the now tiresome phrase: "If we can go to the moon, why can't we do something about . . . (fill in name of problem of the month here)?" Trite as it is, the phrase, in my view, is a tribute to, and a real benefit from, the Apollo program. By achieving something that has for decades, even centuries, symbolized the unattainable ("reach for the moon," etc.), we have raised our standards of what we can do if we try hard enough. And the "tiresome" question is, in fact, an extremely pertinent one. Why *can't* we clean up the Great Lakes? Cure cancer? Prevent war? Save the whales? Perhaps one of Apollo's greatest contributions eventually may lie in its demonstration of the challenges our civilization *can* meet.

SECOND THOUGHTS

This article is intended, as earlier indicated, to be the argument for the affirmative: that the Apollo program *was* worth its cost. But even the most enthusiastic supporters of manned lunar exploration have had doubts about Apollo at one time or another. The fundamental inefficiency of expendable boosters, for example, is obvious, which is why NASA is developing the reusable space shuttle. The first serious plans for space exploration, published in the late 1940s, never involved rockets costing over $100 million that would be used once and discarded; the general concept most widely favored was that of a reusable earth-to-orbit vehicle to build a space station, which would then be used as a re-fueling and checkout site for lunar or planetary orbit-to-orbit spacecraft. With the development of the shuttle, we are now getting back on this much more efficient development path.

The fast pace of the Apollo program was necessary, for reasons of economy, efficiency, and safety. But it had undesirable by-products, one of which was a substantial amount of scientific information that has not been properly assimilated. Attention shifted too quickly from terrain photographs from Apollo 7 to scientific planning for Apollo 8. Before the results were analyzed, the color photographs from Apollo 9 demanded priority, only to be superceded by the priceless haul from lunar landings in Apollo 11 and Apollo 12.

The report of these distractions is not exaggerated. Many scientists have a lot of material that really demands a second and much closer look. But on the positive side, the preliminary analyses that *had* to be done *did* get done; and the film, magnetic tape, and lunar samples are carefully preserved until scientists can get back to them. The experience of being suddenly, so to speak, thrown into space was unbelievably exciting and stimulating. Another positive aspect of this superficially chaotic sequence of missions was that many young scientists were given invaluable exposure to new material and new concepts while reaching their most productive years.

A final doubt about the Apollo program felt by many scientists is the question of whether we could not have explored the moon just as effectively, and much more economically, with unmanned spacecraft. This question deserves more than a superficial answer.

First, it must be pointed out that we *did* use unmanned spacecraft: Ranger, Surveyor, and Lunar Orbiter, and on the Russian side, the Luna, Zond, and Lunokhod series. All were at least partly successful, and cost much less, on a mission-for-mission basis, than did the Apollo program. But the unmanned lunar missions produced far less knowledge about the moon than did Apollo, and virtually no new knowledge in other scientific fields. The Apollo 11 mission alone settled almost at once several major scientific controversies, such as the age of the maria, the composition of the mare material, and the importance of electrostatically-transported dust. Later missions, as we have seen, carried out scores of complex experiments.

"But," critics reply, "what if we had spent as much on unmanned missions as we did on Apollo? We could have gotten comparable results, with no risk to human life." This superficially plausible argument is decisively contradicted by our actual experience with unmanned missions, which have been plagued with difficulties many of which could have been corrected by human intervention. Any unmanned spacecraft practical in this century and complex enough to carry out an Apollo-type mission would have been an engineer's nightmare of moving parts and intricate electronics.

So my answer to the question of unmanned vs. manned lunar missions is that the Apollo program did cost more; but it returned *far* more than unmanned missions, and accomplished complex operations that no feasible unmanned spacecraft could have.

The question "Was the Apollo program worth its cost?" involves a value judgment, and as such can only be answered by each individual. The hope is that this inadequate summary of a 12-year program will show that Apollo made major contributions to science, technology, and, most important, to better understanding among the inhabitants of the earth.

FOOTNOTES

1 The "effectively" refers to the fact that there was an "Apollo" study for a three-man spacecraft underway by NASA before 1961, but it was a low-key project with no definite schedule.

2 National Aeronautics and Space Administration, *Apollo 17 Preliminary Science Report,* SP-330 (Washington, D.C.: U.S. Government Printing Office, 1973).

3 P.D. Lowman, Jr., *The Third Planet* (Zurich: Weltflugbild Reinhold A. Muller, 1972).

4 *The 1973 World Almanac* (New York: Newspaper Enterprise Association, 1972).

5 C.P. Boyle, *Space Among Us* (Washington, D.C.: Aerospace Industries Association of America, Inc., 1974).

6 B. Hoffman, *Albert Einstein, Creator and Rebel* (New York: Viking Press, 1972).

7 F.B. Gibney and G.J. Feldman, *The Reluctant Space-Farers* (New York: New American Library, 1965).

8 *Ibid.,* p. 71

9 There are many accounts of this event. A good one giving the general background is J.N. Wilford, *We Reach the Moon* (New York: Bantam Books, 1969). Political aspects are well-covered by T.C. Sorenson, *Kennedy* (New York: Harper & Row, 1965).

10 *Newsweek,* April 13, 1970, pp. 34-35.

11 The most recent comprehensive text is S.R. Taylor, *Lunar Science: A Post-Apollo View* (New York: Pergamon Press, 1975). A technical review, originally written for students, is P.D. Lowman, Jr., "The Geologic Evolution of the Moon," *Journal of Geology* 80 (1972): 125-166. Apollo preliminary science reports are available from the U.S. Government Printing Office, Washington, D.C.

12 P.D. Lowman, Jr., *Ibid.*

13 In press, *Journal of Geology.* Also summarized in N.M. Short, *Planetary Geology* (New York: Prentice-Hall, 1975).

14 P.D. Lowman, Jr., "The Earth from Orbit," *National Geographic* 130 (November 1966): 644-671.

15 See reference in fn. 2.

16 See reference in fn. 5.

17 National Aeronautics and Space Administration, *Conference on Materials for Improved Fire Safety,* SP-5096 (Washington, D.C.: U.S. Government Printing Office, 1971).

18 A.C. Clarke, *The Promise of Space* (New York: Pyramid Publications, 1970).

19 See *Planetary Geology,* fn. 13.