THE FLIGHT OF APOLLO 11

"ONE GIANT LEAP FOR MANKIND"

BY KENNETH F. WEAVER

This article was originally published in the December 1969 issue of the magazine.

Two thousand feet above the Sea of Tranquillity, the little silver, black, and gold space bug named *Eagle* braked itself with a tail of flame as it plunged toward the face of the moon. The two men inside standing like the motorman in a 19th-century trolley car-strained to see their goal. Guided by numbers from their computer, they sighted through a grid on one triangular window.

Suddenly they spotted the onrushing target. What they saw set the adrenalin pumping and the blood racing. Instead of the level, obstacle-free plain called for in the Apollo 11 flight plan, they were aimed for a sharply etched crater, 600 feet across and surrounded by heavy boulders.

For Astronaut Neil Armstrong, at the controls of the frail, spidery craft, a crisis in flight was nothing new. In 1966 he had subdued the wildly gyrating Gemini 8 when one of its thrusters stuck. More recently, he had ejected safely from the "flying bedstead," a 752 jet-powered lunar-landing training vehicle, just before it crashed. Now he would need all the coolness and skill acquired during 500 earthbound hours in simulators and during years test-flying the X-15 and other experimental aircraft for the National Aeronautics and Space Administration.

The problem was not completely unexpected. Shortly after Armstrong and his companion, Edwin (Buzz) Aldrin, had begun their powered dive for the lunar surface ten minutes earlier, they had checked against landmarks such as crater Maskelyne and discovered that they were going to land some distance beyond their intended target.

And there were other complications. Communications with earth had been blacking out at intervals. These failures had heightened an already palpable tension in the control room in Houston. This unprecedented landing was the trickiest, most dangerous part of the flight. Without information and help from the ground, *Eagle* might have to abandon its attempt.

Moreover, the spacecraft's all-important computer had repeatedly flashed the danger signals "1201" and "1202," warning of an overload. If continued, it would interfere with the computer's job of calculating altitude and speed, and neither autopilot nor astronaut could guide *Eagle* to a safe landing.

CREDIT LINE: Kenneth Weaver/National Geographic Creative.

Eagle's Descent Fuel Runs Low

Armstrong revealed nothing to the ground controllers about the crater ahead. Indeed, he said nothing at all; he was much too busy. The men back on earth, a quarter of a million miles away, heard only the clipped, deadpan voice of Aldrin, reading off the instruments.

"Hang tight; we're go. 2,000 feet."

Telemetry on the ground showed the altitude dropping ... 1,600 feet ... 1,400 ... 1,000. The beleaguered computer flashed another warning. The two men far away said nothing.

Not till *Eagle* reached 750 feet did Aldrin speak again. And now it was a terse litany: "750 [altitude], coming down at 23 [feet per second, or about 16 miles an hour] ... 600 feet, down at 19 ... 540 feet, down at 15 ... 400 feet, down at 9 ... 8 [feet per second] forward ... 330, 3½ down." *Eagle* was braking its fall, as it should, and nosing slowly forward.

But now the men in the control room in Houston realized that something was wrong. *Eagle* had almost stopped dropping, but suddenly—between 300 and 200 feet altitude—its forward speed shot up to 80 feet a second—about 55 miles an hour! This was strictly not according to plan.

At last forward speed slackened again and downward velocity picked up slightly.

"Down at 2½ [feet per second], 19 forward ... 3½ down, 220 feet [altitude] ... 11 forward, coming down nicely, 200 feet, 4½ down ... 160, 6½ down ... 9 forward ... 100 feet."

And then, abruptly, a red light flashed on *Eagle's* instrument panel, and a warning came on in Mission Control. To the worried flight controllers the meaning was clear. Only 5 percent of *Eagle's* descent fuel remained. By mission rules, *Eagle* must be on the surface within 94 seconds or the crew must abort (give up) the attempt to land on the moon. They would have to fire the descent engine full throttle and then ignite the ascent engine to get back into lunar orbit for a rendezvous with *Columbia*, the mother ship.

When only 60 seconds remained, the countdown began. The quivering second hands on stopwatches began the single sweep that would spell success or failure.

"Sixty seconds," called Astronaut Charles Duke, the capsule communicator (CapCom) in Houston. Sixty seconds to go. Every man in the control center held his breath.

Failure would be especially hard to take now. Some four days and six hours before, the world had watched a perfect, spectacularly beautiful launch at Kennedy Space Center, Florida. Apollo 11 had flown flawlessly, uneventfully, almost to the moon. Now it could all be lost for lack of a few seconds of fuel.

"Light's on." Aldrin confirmed that the astronauts had seen the fuel warning light.

"Down 2½ [feet per second]," Aldrin continued. "Forward, forward. Good. 40 feet [altitude], down 2½. Picking up some dust. 30 feet. 2½ down. Faint shadow."

He had seen the shadow of one of the 68-inch probes extending from *Eagle's* footpads.

"Four forward ... 4 forward, drifting to the right a little."

“Thirty seconds,” announced CapCom. Thirty seconds to failure. In the control center, George Hage, Mission Director for Apollo 11, was pleading silently: “Get it down, Neil! Get it down!”

The seconds ticked away.

“Forward, drifting right,” Aldrin said.

And then, with less than 20 seconds left, came the magic words: “Contact light!”

The spacecraft probes had touched the surface. A second or two later Aldrin announced, “O.K., engine stop.”

Still later, the now-famous words from Neil Armstrong: “Tranquillity Base here. The *Eagle* has landed.”

And, with joy in his voice, CapCom replied: “Roger, Tranquillity, we copy you on the ground. You got a bunch of guys about to turn blue. We’re breathing again. Thanks a lot.”

It was 4:17:43 p.m., Eastern Daylight Time, Sunday, July 20, 1969.

Feat Watched by the World

Man’s dream of going to the moon was fulfilled. The most exciting adventure in human memory now neared its climax as the two men prepared to step out on the lunar surface, while their fellow crew member, Mike Collins, kept vigil in his orbiting command module, *Columbia*, 70 miles above.

To me, it is impossible to compare this exploit with the epic feats of the great 15th- and 16th-century navigators, of the 20th-century polar explorers, or of Lindbergh in 1927. The differences are too profound, and one of the most important of those differences is that the whole world was watching.

According to estimates, one out of every four persons on the face of the earth watched or heard the astronauts by television or radio as they ventured to the moon. Nearly 850 foreign journalists, representing 55 countries and speaking 33 languages, reported the story from Cape Kennedy and Houston.

Americans abroad were thrilled by the impact of the flight on foreign peoples. Dr. Louis B. Wright, former Director of the Folger Shakespeare Library and a National Geographic Society Trustee, observed the effect firsthand in Italy. With 25,000 other people he was attending a performance of *Aida* in the Roman Arena at Verona on that Sunday night.

“At the first intermission,” Dr. Wright recalls, “an announcement was made in four languages: ‘The Americans have just landed on the moon at 10:17.’ My watch said 10:28.

“The crowd applauded wildly. Here and there spectators pulled little United States flags from their pockets and waved them. And for days afterward, when Italians met me on the street, they all had one word for the flight—‘Fantastico!’”

And so it was—with different inflections—in Buenos Aires and Sydney, Tokyo and Delhi, Dublin, and Madrid.

The thrill of a race had added to the excitement. Since 1961, when President John F. Kennedy had announced the goal “before this decade is out, of landing a man on the moon and returning him safely to the earth," many people had firmly believed that the Soviet Union was racing to put a Russian on the moon first.

In the past year or so, Soviet chances had seemed to dim, but as Apollo 11 approached the moon, the news that Luna 15 was already in lunar orbit lent color to the suspicion that the Soviets hoped to land an unmanned craft, scoop up some lunar soil, and rush back to earth before the American moon samples could get home. Only when Luna 15 crashed in Mare Crisium—the Sea of Crises—some 500 miles from Tranquillity Base, was the way clear for the U. S. triumph.

That triumph was an especially heady one for those who argued the advantages of manned space flight. Without a man at the controls, they pointed out, *Eagle* would almost certainly have crashed into an unforgiving field of boulders.

The full story became known only after the astronauts returned to earth. When Neil Armstrong first spotted the landing site through the grid on his window, he did not really know where he was. Actually the crater toward which he was heading—later identified as "West Crater" (an unofficial name) was just within the southwest edge of the planned landing ellipse, a bull's-eye 7.4 miles long and 3.2 miles wide. But most of the landmarks the astronauts had memorized so carefully before the flight were several miles behind them, and were of no help now.

Armstrong had no doubts, however, about what to do; he had faced problems like this many times before in the simulators.

Taking over partial control from *Eagle's* autopilot, he ordered the computer to keep the craft at a steady altitude and gave *Eagle* its head, reducing the braking effect of the descent engine and letting the craft surge forward at high speed.

Only when he had shot over West Crater and its frightful rocks ("as big as Volkswagens"), and had cleared a second, smaller crater 100 feet in diameter, did he bring the descent engine's braking power into full play again and drop to a level, relatively clear spot.

During the last forty feet or so of descent, the rocket-engine exhaust sent the dust of the moon flying. Not billows of dust; instead, the disturbed particles flew out at low angles and high velocity, like rays of light, with no atmosphere to buoy them or impede them. Armstrong later described it as "much like landing through light ground fog." The moment the engine shut off, however, the view out the window was completely clear again.

Armstrong's maneuver took him more than 1,000 feet beyond where the autopilot would have set him down, cost an extra 40 seconds, and left only about 2 percent of usable fuel—about 400 pounds—for the descent engine.

But it meant a safe landing, and a gentle one—so gentle that the two men hardly felt it. Armstrong says that their downward speed was probably no more than one foot a second. And the footpads of the eight-ton craft (it weighed only a sixth of that on the moon) settled just an inch or two into the surface.

Space Suits Balk Lunar Hazards

Inside the spacecraft, Armstrong and Aldrin set calmly about making sure they could get home again. They carefully worked through their check lists to assure that all the systems were working, that the supplies of oxygen and fuel were satisfactory, and that the ascent engine would be ready when needed.

Then history's first lunar explorers completed the laborious task of suiting up for their excursion onto the moon's surface. To their many-layered space suits, marvels of engineering that work like Thermos bottles and that can stop micro-meteoroids traveling at 64,000 miles an hour—30 times the speed of a military rifle bullet—they added other ingenious protections against the hazards of the moon's environment: heavily corrugated plastic overboots that can resist temperatures from 250 degrees above zero F. to 250 degrees below; gloves covered with fine metal mesh (a special alloy of chromium and nickel)—worth $1,000 a yard—to protect the glass-fiber and Teflon material from abrasion; hoods for their transparent bubble helmets, with double visors (both of them coated with gold) to block the sun's intense glare, heat, and ultraviolet radiation.

Finally each donned a remarkable backpack known as the PLSS (portable life support system) to provide cooling water, electric power, communications, and oxygen enough to last four hours outside the lunar module without replenishing. The men had become, in effect, independent spacecraft.

All this added nearly 190 pounds to each man's earthly weight. Although that means only about 32 pounds on the moon, it alters the center of gravity and hampers activity. The suit, when pressurized, becomes so hard that hitting it with the fist would be like striking a football. Bending over to the ground is extremely difficult.

I have some idea of how all this paraphernalia must feel: I once tried on Astronaut Gene Cernan's suit and helmet. Under earthly conditions, I found them heavy, cumbersome, and slightly claustrophobic. But no astronaut complains. Should his space suit lose pressure, he would keep useful consciousness, as pilots say, for only 8 to 12 seconds.

First Step Beamed to a Waiting World

About six and a half hours after *Eagle* landed, its hatch opened and the Apollo 11 commander backed slowly out to its little porch. On the ladder he paused, pulled a lanyard, and thus deployed the MESA, or modularized equipment stowage assembly, just to the left of the ladder. As the MESA lowered into position with its load of equipment for lunar prospecting, a seven-pound Westinghouse TV camera mounted atop the load began shooting black-and-white pictures. Fuzzy and scored with lines, the pictures nonetheless held earthlings spellbound.

No one who sat that July night welded to his TV screen will ever forget the sight of that ghostly foot groping slowly past the ladder to *Eagle's* footpad, and then stepping tentatively onto the virgin soil. Man had made his first footprint on the moon.

Neil Armstrong spoke into his microphone. And in less than two seconds the message that will live in the annals of exploration flew with the wings of radio to the huge telescope dish at Honeysuckle Creek, near Canberra, Australia, thence to the Comsat satellite over the Pacific, then to the switching center at the

Goddard Space Flight Center outside Washington, D. C., and finally to Houston and the rest of the world: "That's one small step for a man, one giant leap for mankind."

Lunanauts Move Easily on the Moon

At last man was seeing before his eyes answers to a host of riddles that had perplexed and divided scientists and intrigued other mortals. Could man perform at the moon's ⅙ g (⅙ of earth's gravity)? Would he sink into a sea of soft, smothering dust? Would fatigue quickly claim him?

And what about the lunar material? Would it be young or old, hard or soft, black or brown or gray? Would it be volcanic? Would it duplicate material on the earth? Would it tell the story of a hot moon or a cold moon?

Obviously the lunanauts had little difficulty performing in ⅙ g. After gingerly testing the soil and the best ways of moving, they frolicked about like colts, or—as Apollo 8 Astronaut Bill Anders remarked—like a pair of Texas jack rabbits. They tried two-legged kangaroo jumps; that technique proved tiring. They floated across the long-shadowed scene in a lazy lope, six to eight feet at a stride, with both feet in the air most of the time. It felt like slow motion, Armstrong reported, but it was a comfortable way to cover ground—if they remembered to plan their stops three or four steps ahead.

At times they seemed, in their bulky suits, like dancing bears; at other times they were marionettes. And now and then it was a ballet, with a graceful pas de deux.

Their exuberance was seen not only in their lively actions but also in Armstrong's excited query right after Aldrin came down the ladder: "Isn't it fun?"

But it was hard work too, with many scientific observations to make and tasks to perform in a tightly limited schedule.

As for the surface, at least in the Sea of Tranquillity, the *Eagle* crew said it was somewhat slippery and described the soil as seeming like graphite, or soot, or almost like flour. It stuck to their boots, but because of the moon's lack of air, it never billowed up to hamper work.

They said that their boots pressed in only a fraction of an inch in most places, although on the edges of small craters they sank as much as six or seven inches and tended to slip sideways.

In fact, the two men discovered a strange paradox: When they planted the United States flag in the lunar soil, they had to press hard to force the staff down, yet it would fall over easily. The soil showed great resistance downward, but little sideways. Aldrin found that he could pound a core tube only about five inches deep, even with repeated blows.

The men remarked on the variety of the moon rocks. The surface of some showed vesicles, or tiny pits, formed by gas bubbles as the rock cooled. Some were pitted with little glassy craters as though they had been struck by BB shot.

Colors varied from chalky gray to ashen gray, with hints of tan or cocoa brown at times, depending on the angle of view.

Moon Rocks Hold High Priority

In every direction, the lunar surface was pocked with thousands of little craters and many larger ones, five to fifty feet across and littered with angular blocks.

It had been decided in advance that the most important single thing the astronauts could do—scientifically speaking—would be to bring back samples of the moon.

Shortly after stepping onto the surface, Armstrong took a "grab sample," or contingency sample, scooping it up into a Teflon bag on the end of a light collapsible rod. The pole he discarded, but the bag of soil he rolled up and—with some difficulty—tucked into a pocket above his left knee.

As Astronaut-scientist Don Lind commented in Houston during the flight, "He is certainly going to get back in the spacecraft with his pants on, so we will have this sample for sure."

With a specially made aluminum scoop on an extension handle, and with a pair of long aluminum tongs, Armstrong later gathered a larger quantity of the dark lunar soil and representative samples of the lunar rocks. These he put into two boxes, each formed from a single piece of aluminum. A ring of soft metal, indium, lined the lip of each box; when the box was closed and the straps drawn tight around it, a knifelike strip around the edge of the lid bit deeply into the indium, thus helping to seal the samples in a vacuum and to protect them against contamination.

All told, the astronauts brought back about 48 pounds of lunar material. In addition, they undertook to gather a bit of the sun. To be sure, it was a very small sample, less than a billionth of an ounce at best, but presumably it was enough to tell a great deal about the solar furnace. The sample was gathered by trapping particles of the solar wind.

Swiss Scientists Count Sun Particles

The solar wind is an ionized, or electrified, gas constantly streaming away from the sun at speeds of 200 to 400 miles a second. Ordinarily we do not detect the wind on earth, because the magnetosphere—the magnetic field around our planet—deflects the electrified gas. We see its effects only when a little of the solar wind occasionally leaks into the magnetosphere in the polar regions, becomes accelerated by some process that scientists do not yet understand, and causes the brilliant aurora high in the atmosphere.

The moon lacks a strong magnetic field, so the solar wind flings against it a steady barrage of atomic particles that, scientists believe, may slowly erode the lunar rocks. The device to trap these infinitesimal particles is ingeniously simple, compared to other more sophisticated instruments designed for lunar research. It amounts to little more than a strip of aluminum foil about a foot wide and four and a half feet long that Aldrin unfurled and hung on a slender mast stuck into the moon near the lunar module.

This sheet was left exposed to direct sunlight for an hour and 17 minutes, then rolled up like a window shade and stored inside one of the lunar sample boxes. Scientists hope that during exposure the sheet received the full force of the solar particles. Many of them—perhaps as many as 100 trillion—may have embedded themselves in the foil, penetrating several times their own diameter—as much as a millionth of an inch.

As this is written, Swiss researchers led by Dr. Johannes Geiss are attempting to extract the solar particles at the University of Bern and the Federal Institute of Technology in Switzerland.

Their technique is to melt and vaporize the foil in an ultrahigh vacuum. Then, in a device known as a mass spectrometer, the atomic particles of the gases they are seeking may be separated according to their mass. The process faintly resembles that of the cream separator which drives the heavier milk particles to one outlet and the lighter cream particles to another.

Unmanned satellites outside our atmosphere have already investigated the solar wind, and from these studies scientists have found that it holds particles of hydrogen, helium, and probably oxygen. Theoretically it should also contain particles of all the other chemical elements making up the sun—some 92 in all. The Swiss researchers do not expect to detect all these; rather, they seek to measure the gases helium, neon, and argon, known as "noble gases" because they normally do not react with other substances.

Dr. Geiss hopes to find isotopes, or varieties, of these elements in the foil-trapped solar wind sample. Knowledge about the proportions of such isotopes will add to our understanding of the origin of the solar system. Particularly it may tell us something of how the earth and its atmosphere were formed.

Unique Instruments Gleam Like Jewels

The solar wind collector came back to earth with the astronauts, but two other important scientific instruments were left behind on the moon. One is a seismometer, a device for detecting tremors and quakes. The other is a super-mirror to reflect laser beams sent up from earth. Together they form the EASEP, or early Apollo scientific experiments package.

I was privileged to see these two instruments a few days before they were placed aboard the lunar module. As befits all hardware going on moon flights, they were kept in a "clean room," where all dust is carefully filtered out. Before going in, I had to thrust my shoes into a mechanical brusher to remove dust, then cover my clothing with a white nylon gown and my hair with a nylon cap.

The two instruments stood in solitary splendor in the middle of the floor, completely dominating an otherwise nearly empty room. A barrier surrounded them, keeping me at a discreet distance. Lights bathed the scene from a high ceiling, reflecting on white walls and an aluminum floor. I felt as though I were in a sultan's treasury, looking at his crown jewels. And, in truth, the two devices shone and glittered like jewels—the seismometer because of its amber-gold thermal covering, and the reflector because of the crystalline beauty of its 100 glistening prisms.

Inside the golden cylinder at the heart of the seismometer were mechanical combinations of booms, hinges, and springs that respond to vibrations, and electronic devices to record the intensity of the vibrations and transmit the information by radio to earth. Two large solar panels, producing as much as 40 watts, could provide the necessary electric power during the two-week-long lunar day. During the moon's night the instrument was to fall silent, but nuclear heaters, fueled with radioactive plutonium 238, would keep the transmitter warm.

Device to Measure Lunar Tides

Dr. Gary V. Latham of Columbia University's Lamont-Doherty Geological Observatory, the principal investigator for the seismometer experiment, told me that this kind of instrument has given us most of what we know about the earth's interior, and should do the same for the moon.

"However, the lunar seismometer is ten to a hundred times more sensitive than those we use on earth," he explained. "The moon fortunately lacks the constant vibrations from ocean tides, wind, and traffic that plague instruments on earth.

"With this device—actually four seismometers in one package—we should be able to detect the impact of a meteorite the size of a garden pea half a mile away on the moon.

"Also, in time we should be able to tell if there are small tilts in the surface caused by tides in the lunar material itself. If a rigid bar 300 miles long were lifted at one end by one inch, this seismometer could record it.

"And the instrument can record tremors about one million times smaller than the vibration level that a human being can feel."

I asked Dr. Latham how he could tell the difference between a moonquake and a meteorite impact.

"It's not easy," he admitted, "but that's about the same problem seismologists have been facing for years in deciding whether a tremor on earth is caused by a quake or by a nuclear test in some remote place. We can do it because the waves caused by a bomb or an impact are richer in high-frequency vibrations than those caused by a quake."

On the moon, Buzz Aldrin opened an equipment bay on the back of the lunar module and lifted out the two instruments—weighing a total of nearly 170 pounds—as though they were light suitcases. He carried them easily, with both arms bent at the elbows so the packages would not chafe his suit. He deployed the seismic package about 60 feet away from *Eagle* while Armstrong set up the laser reflector nearby, where they would presumably not suffer from the blast of the ascent engine.

A few minutes later, a radio command from earth uncaged the seismometers and turned on their transmitter. Immediately—to the joy of scientists on earth—the instruments began recording the footfalls of the astronauts on the moon.

Inked Squiggles Record Moon's First Visitors

In the control center at Houston, I watched signals coming in from the seismometers. Inked pens traced endless lines on long strips of paper issuing from strip-chart recorders; heated styluses did the same on waxed paper on drum recorders.

Dr. Latham explained that when the lines were straight, the moon was quiet. When the pens and styluses began to vibrate and trace squiggly lines, something was happening on the moon. The nature of the squiggles and their amplitude suggested to Dr. Latham and his colleagues what was happening. For example, rapid vibrations of the pens, tracing designs like fuzzy caterpillars, recorded the movements of the astronauts.

The moon seems to be quieter internally than earth—but the instruments have nonetheless recorded trains of high-frequency waves lasting from one to nine minutes. These, say the scientists, may be landslides, perhaps in West Crater. It is a new enough crater for such slides to be expected from the stresses caused by constant shifts from extreme heat to extreme cold.

The seismometers also seemed to detect several fairly strong shocks with lower frequencies than the landslide tremors. At first these appeared to be moonquakes. But peculiarities in the signals have led the seismologists to suspect that the "tremors" may have been caused by venting of gases from the lunar module, or by abnormalities within the instruments themselves. Only further experiments will tell.

The Apollo 11 seismometers survived the oven heat of one lunar noon and the bitter cold of one lunar night, but the electronics in their command receiver gave out from overheating on the second noon. Dr. Latham expects the instruments carried on future missions to last longer because they will be protected with a heat-radiating thermal blanket.

Laser Hits a Far-off Target

As soon as Neil Armstrong had put the laser reflector in place and carefully aimed it at earth, scientists began firing powerful pulses of ruby laser light at it. The second and third largest telescopes in the world (after Mount Palomar's)—the 120-incher at Lick Observatory, on Mount Hamilton, California, and a brand-new 107-incher at McDonald Observatory, Fort Davis, Texas—were used to concentrate the beams. Light passing backward through one of these telescopes spreads out to a spot only a few miles wide by the time it hits the Sea of Tranquillity.

At first no detectable light returned; the brilliance of reflected sunlight obscured whatever laser light might be struggling back. But shortly before lunar night, the telescope at Lick began to pick up signals, and McDonald has since detected them repeatedly.

Unlike the seismic package, the laser reflector has no moving parts and requires no power supply. It consists simply of a hundred fused-silica prisms, each about the width of a silver dollar, set in an aluminum frame 18 inches square. Each prism is the corner of a cube. When light enters and strikes one face, it must, by the laws of optics, bounce off two other faces as well, and then come right back out on itself.

Professor Carroll O. Alley, Jr., of the University of Maryland, who is in charge of the experiment, showed me one of the prisms. As I looked into it, the image of my eye filled the corner where the three planes intersected.

"Now tilt the reflector a few degrees in each direction," suggested Professor Alley.

To my surprise, my eye kept looking straight back at me no matter which way I tilted the piece of silica. It was uncanny that I could not escape its fixed stare.

"That's why the corner reflector works so well for our purposes," explained Professor Alley. "These prisms are the most accurate reflectors ever made in any quantity. Yet, of course, the beam is severely attenuated in its half-million-mile round trip."

How much, I wondered.

"We send out about 10 billion billion photons [units of light]," he said. "If we are lucky, 10 photons will return to our detector. That's far too few for the eye to see, but our instruments can measure them."

Knowing the speed of light, and timing the round trip (about 2½ seconds) to an accuracy of one billionth of a second, Professor Alley and his colleagues can figure the distance to the reflector with an exactness never before possible. They expect to refine that distance, as measured at any given moment, to an error of only six inches—and that's exactly the point of the experiment.

"Once we can determine the moon's distance from two observing spots on earth simultaneously," Professor Alley continued, "then by simple calculation we can find out exactly how far apart those two spots lie. If distances between observatories in Europe and the Americas tend to increase over a period of years, then we will have strong evidence that those continents are slowly drifting apart, as many scientists now believe."

Within a decade the laser experiment will also help scientists check on how fast the moon is receding from the earth, examine the wobble of the earth on its axis, and test new theories of gravity.

Professor Alley expects that the reflector will continue to give good results for at least ten years, maybe a hundred. During that time anyone can use it who has the appropriate laser and telescope equipment. It is truly an international experiment.

Even before Armstrong and Aldrin had finished their observations, photography, and scientific chores, the flight controllers in Houston were getting nervous that the two men would overstay their time on the surface of the moon.

At one point Armstrong loped some 200 feet to photograph the smaller of the two craters he had overflown. "When he returned he was really puffing," one of the men in the control room at Houston told me later. And when the Apollo commander hauled the rock-sample boxes through *Eagle's* hatch with a line-and-pulley arrangement, the exertion sent his pulse up to 160 beats a minute—four beats faster than it had been during the lunar landing.

Those Who Follow Will Stay Longer

But the controllers' fears were groundless. Armstrong entered the LM and locked the hatch just two hours and 20 minutes after he had stepped out of it, almost exactly according to plan. He did not feel particularly tired.

"It was nothing at all like the exhaustion after a football game," he said later.

In fact, the metabolic rate for both men stayed considerably lower than expected. Half their oxygen supply remained unused in their portable life-support packs, as did ample water and battery power. For that reason, the astronauts of Apollo 12 were given permission to stay substantially longer on the moon.

When Aldrin and Armstrong re-entered *Eagle*, one incident aroused momentary apprehension among TV watchers back on earth. One of the backpacks, which barely cleared the hatch entrance, struck a circuit breaker just inside and snapped its end off. It was needed to arm the ascent engine—a necessary step before the engine could be fired to get the men off the lunar surface.

Fortunately, the circuit breaker could still be pushed in. More important, there were other ways in which the astronauts could arm the engine. Almost everything in Apollo can be accomplished in two or more ways for safety's sake.

Before leaving the moon, the two men opened the hatch once more and jettisoned their backpacks and other items not destined for return to earth. (The lunar seismometers dutifully recorded the impacts.)

Million-dollar Museum on the Moon

Any future explorers who reach Tranquillity Base will find an expensive museum. There remain the two lunar instruments, the United States flag (which does not, incidentally, constitute a territorial claim by the United States), *Eagle's* descent stage with the plaque on one leg announcing that "We came in peace for all mankind," and a symbolic olive branch in gold.

And scattered about lie a million dollars' worth of discarded items that had to be left behind to save weight and space: cameras, backpacks, tools, lunar overboots, bags, containers, armrests, brackets, and other miscellaneous gear.

In addition, the crew left an Apollo shoulder patch commemorating the three astronauts—Gus Grissom, Ed White, and Roger Chaffee—who died on January 27, 1967, in a spacecraft fire, and medals honoring two Soviet cosmonauts who have lost their lives—Yuri Gagarin and Vladimir Komarov.

A final memento carried messages of good will from leaders of 73 nations. Etched on a 1½-inch disk of silicon by the same process used for making miniaturized electronic circuits, the messages have been reduced in size 200 times and are invisible to the naked eye.

Eagle's climb back into orbit took less than eight minutes of firing by the ascent engine. Mike Collins, who had been the solar system's most isolated man in his orbiting command module, watched his companions return with undiluted joy. *Eagle* started as a pinpoint of light as its tracking beacon flashed, but grew rapidly in size till it swung grandly into position for rendezvous.

For a few moments during docking, the two craft failed to align themselves properly, but skillful jockeying by the pilots solved the problem. Then Collins floated into the tunnel between *Eagle* and *Columbia* to shake hands with his colleagues.

The three men, reunited in the command module, set the ascent stage adrift in lunar orbit, where it will remain indefinitely, and began the 60-hour journey home. As uneventful as the trip out, the coast back ended on July 24 with a fiery but totally successful reentry in the Pacific, 950 miles southwest of Honolulu.

Emerging from the blackened command module, the three men began a period of earthly quarantine. Wearing biological isolation garments—coveralls with gas masks—they went immediately from the helicopter to a specially adapted vacation trailer known as the mobile quarantine facility. Carried by ship to Hawaii and thence by plane to Houston, they entered living quarters in the Lunar Receiving Laboratory, where they underwent the most intensive medical scrutiny.

None of the tests of the men or of the lunar samples they brought back revealed any organisms that could harm life on earth—or indeed any organisms at all. So, late on August 10, the three Apollo crewmen were released to their families and a waiting world.

What Did Apollo Mean?

Amid all the excitement and hyperbole, what was the real significance of Apollo 11?

In a minor sense, perhaps, it was the coming of age of the space program, for it was the 21st manned space flight for the United States, as well as the 21st launch in the Saturn series. And if life begins at 40, that too is symbolic, for the day after the flight began marked the 40th anniversary of Robert Goddard's first launching of an instrumented rocket, complete with thermometer, barometer, and camera.

Apollo 11 was in addition a momentous adventure, the most widely shared adventure in all history.

It was, as well, a technological triumph of the highest order, made possible only by the sustained effort during the past decade of hundreds of thousands of persons and the expenditure of some 22 billion dollars.

It involves so complex a technology that no one man can begin to comprehend what lies behind it: the tons of blueprints, the 20 thousand contractors; the 20 million pages of manuals, instructions, and other material printed monthly by the Kennedy Space Center alone; the rocket and spacecraft encompassing more than five million separate parts; the engines—most powerful in the world—that gulp 15 tons of kerosene and liquid oxygen a second and get five inches to the gallon; the telemetry that during launch sends back to Houston each second enough information to fill an encyclopedia volume.

Man's Long Reach to the Unknown

But above all, Apollo 11 was a triumph of the human spirit. As Buzz Aldrin said in a TV broadcast while coming home from the moon, "This has been far more than three men on a voyage to the moon ... This stands as a symbol of the insatiable curiosity of all mankind to explore the unknown."

At the President's dinner honoring the astronauts shortly after their release from quarantine, Neil Armstrong brought tears to the eyes of many when he said, in a voice filled with emotion: "We hope and think ... that this is the beginning of a new era, the beginning of an era when man understands the universe around him, and the beginning of the era when man understands himself."

But with all the congratulations, and all the pride of accomplishment, Buzz Aldrin struck perhaps the finest note of all when, on the way home from the lunar conquest, he read to a listening world this moving passage from the eighth Psalm of the Old Testament: "When I consider thy heavens, the work of thy fingers, the moon and the stars, which thou hast ordained; What is man, that thou art mindful of him?"