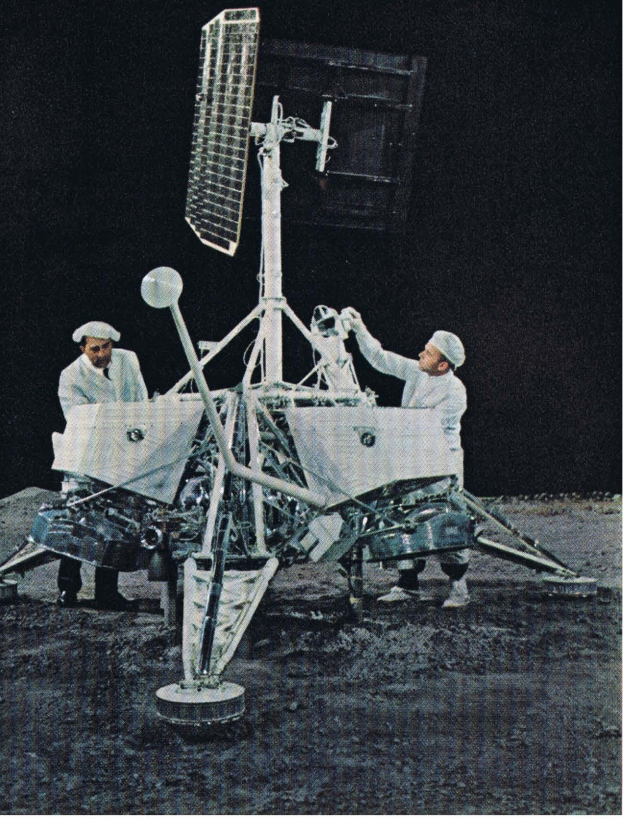
VOL. 130, NO. 4 OCTOBER, 1966

NATIONAL GEOGRAPHIC

THE JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY WASHINGTON, D. C.



Identical twin of moon-borne Surveyor I crouches on lunarlike rubble for inspection by technicians of Hughes Aircraft Company, builders of the vehicle for the National Aeronautics and Space Administration. Tests with this model helped perfect the sister ship that made last June's landing and took more than 11,000 photographs.

Surveyor: Candid Camera on the Moon

By HOMER E. NEWELL, Ph.D.
Associate Administrator, NASA

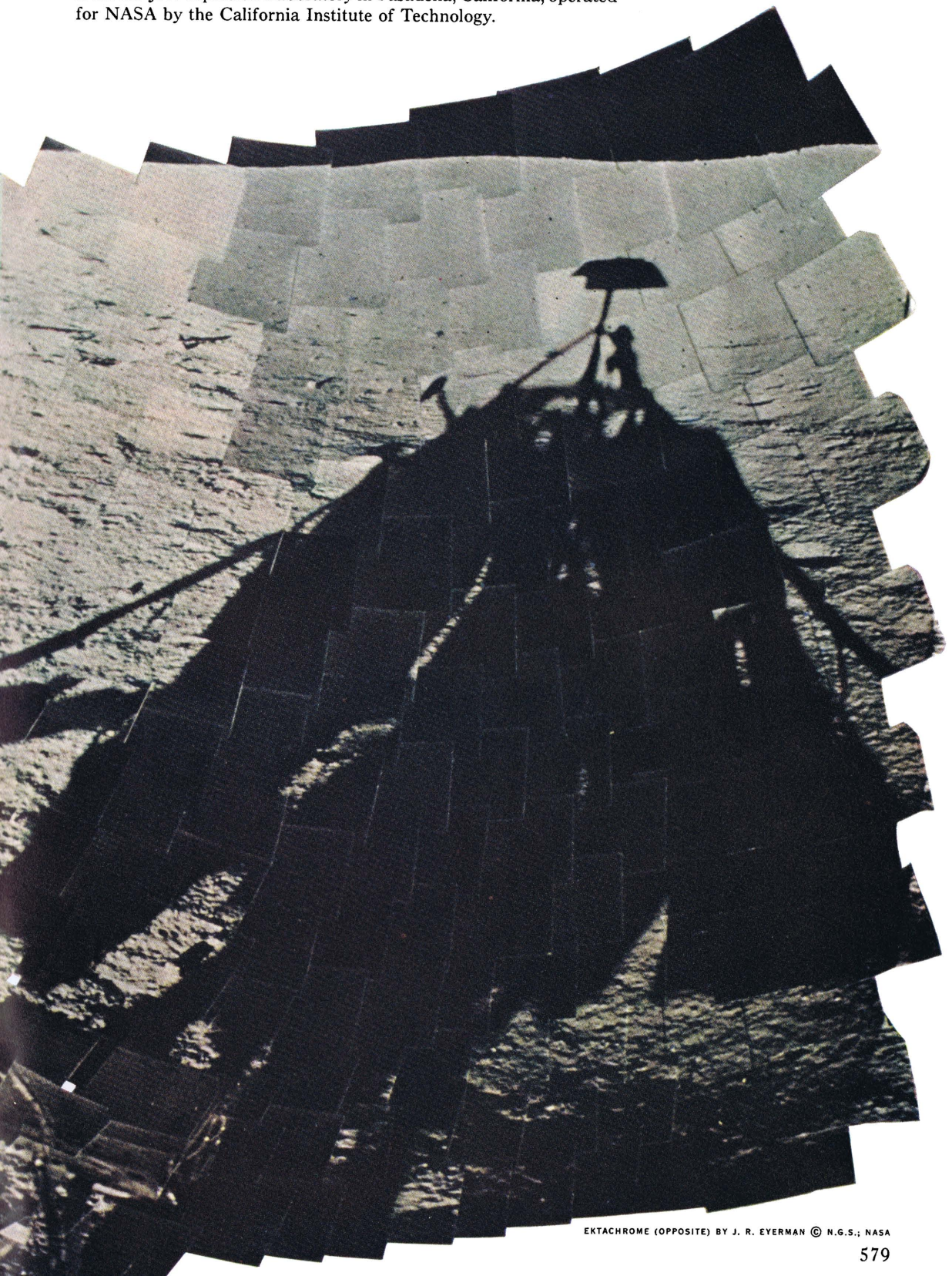
TODAY, on a gray and desolate plain of the moon's Ocean of Storms, Surveyor I stands lifeless, a solitary artifact of men who live on another body of the solar system, 240,000 miles away.

Surveyor proved its ability to survive the furnace heat of the lunar noon, then go through the deep freeze of the 14-day-long lunar night at temperatures nearly 500 degrees colder, and still operate.

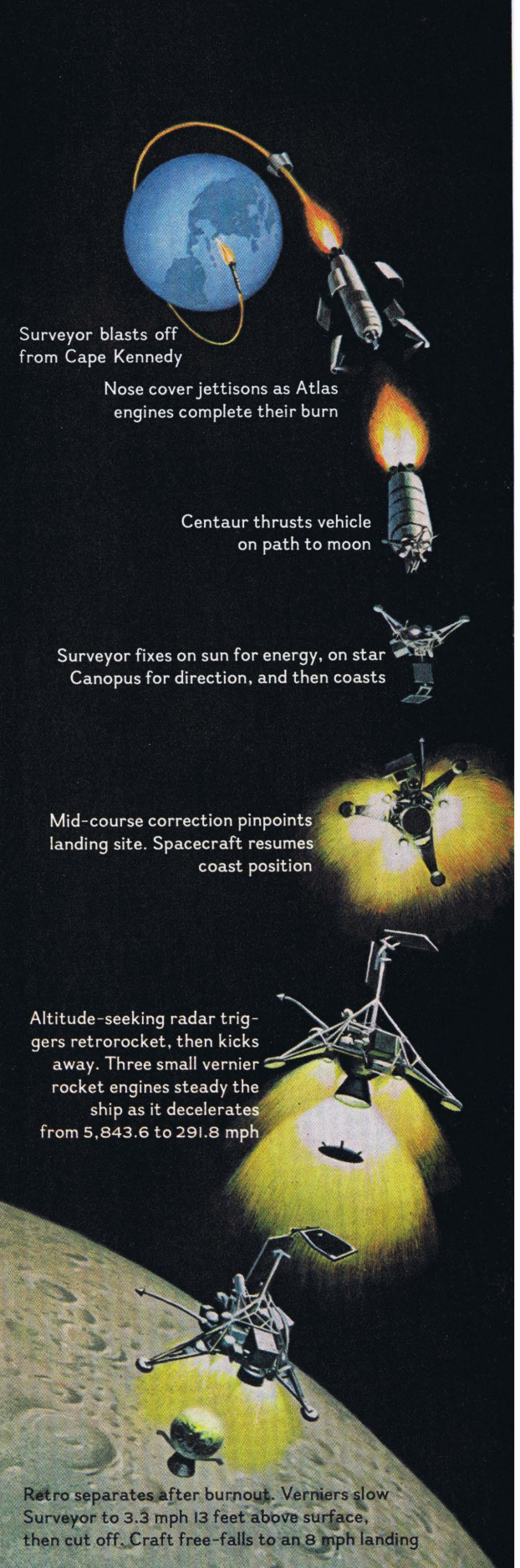
But now its batteries are dead; its antennas are useless; its solar panel and cyclopean camera eye stare blindly.

Surveyor I is silent, but in its brief life its performance far surpassed our hopes. By television it sent us more than 11,000 splendid pictures from the moon, including the first color

Haunting self-portrait of man's moon scout: Surveyor throws its sixty-foot shadow across rocky terrain Apollo astronauts may tread three years from now. Scanning to the horizon, roughly a mile away, Surveyor sent back hundreds of "chips," from which this striking mosaic emerged. Scientists controlled the robot by radio commands from the Jet Propulsion Laboratory in Pasadena, California, operated for NASA by the California Institute of Technology.



EKTACHROME (OPPOSITE) BY J. R. EYERMAN © N.G.S.; NASA



photographs (opposite and page 589). It gave us a remarkably clear and intimate view of the lunar face, so close that we can measure and count particles only a fiftieth of an inch across. It even provided us with a glimpse beneath the moon's surface.

For the first time, because of Surveyor, Project Apollo officials feel real assurance that an astronaut can safely set foot on the moon, that the moon's surface will support him, and that he will not be swallowed up in a thick sea of dust.

Further, Surveyor added substantially to our meager knowledge of earth's natural satellite—information that we will be analyzing and digesting for months to come.

Even more, as Robert Parks, Surveyor Project Manager at the Jet Propulsion Laboratory in Pasadena, California, has pointed out, "The spacecraft gave us an engineering miracle. Its flight and landing worked exactly as expected. On its journey and on the moon, it answered almost flawlessly more than 100,000 radio commands sent principally through our huge antenna at Goldstone, in California's Mojave Desert."

We also used similar antennas near Johannesburg, South Africa, and at Tidbinbilla, near Canberra, Australia.

Surveyor Aim Only Nine Miles Off

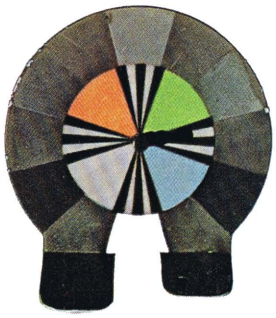
Consider, for example, Surveyor I's accuracy. It was launched May 30, 1966, from a point on earth rotating at about 870 miles an hour, at a target moving some 2,300 miles an hour. Sixty-three hours and 36 minutes later, after traveling almost a quarter of a million miles, and with only one minor correction during its flight, it landed within nine miles of its target on the west side of the moon, close to the lunar equator.

Stephen E. Dwornik, Program Scientist for Surveyor, estimates that an expert rifleman firing at a fast-moving bull's-eye 250 yards away would have to hit within the thickness of this magazine to do as well.

Once in the vicinity of the moon, Surveyor's ultrasensitive radar began feeding to its self-contained computer information about its velocity and altitude. The main retrorocket, triggered by the altitude-marking radar, slowed the spacecraft's hurtling descent from 5,800 miles an hour to 290 miles an hour in 40 seconds. Then, small vernier rocket engines almost stopped it a few feet above the surface. Like some giant insect with its spindly

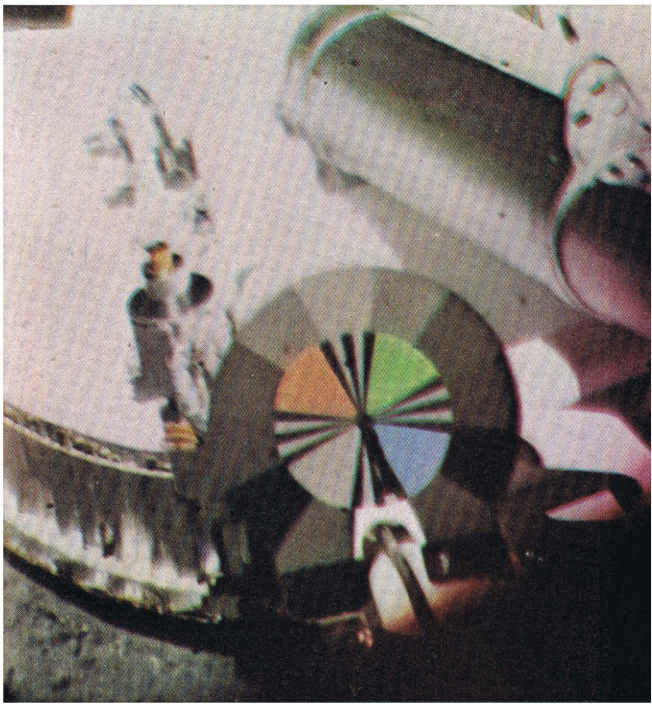
(Continued on page 587)

DIAGRAM BY DAVIS MELTZER © NATIONAL GEOGRAPHIC SOCIETY



Moon's gray pallor contrasts with color targets attached to Surveyor in these epoch-making photographs. The craft snapped color pictures of the moon, but not on color film. Instead, its camera shot three separate pictures of each scene—through orange, green, and blue filters. Working under the supervision of JPL scientists, the Geographic's color laboratory took the separation negatives transmitted from the moon and printed them through filters onto one piece of color film.

Close-up at right shows a gold-plated jet nozzle that appears yellow against Surveyor's white frame. Magenta tint came from failure of the camera's green filter to register properly. Photometric disks, identical to one at JPL (inset), provided the guide for reconstituting the color. Subtle color differences between small features help geologists interpret the moon's surface structure.



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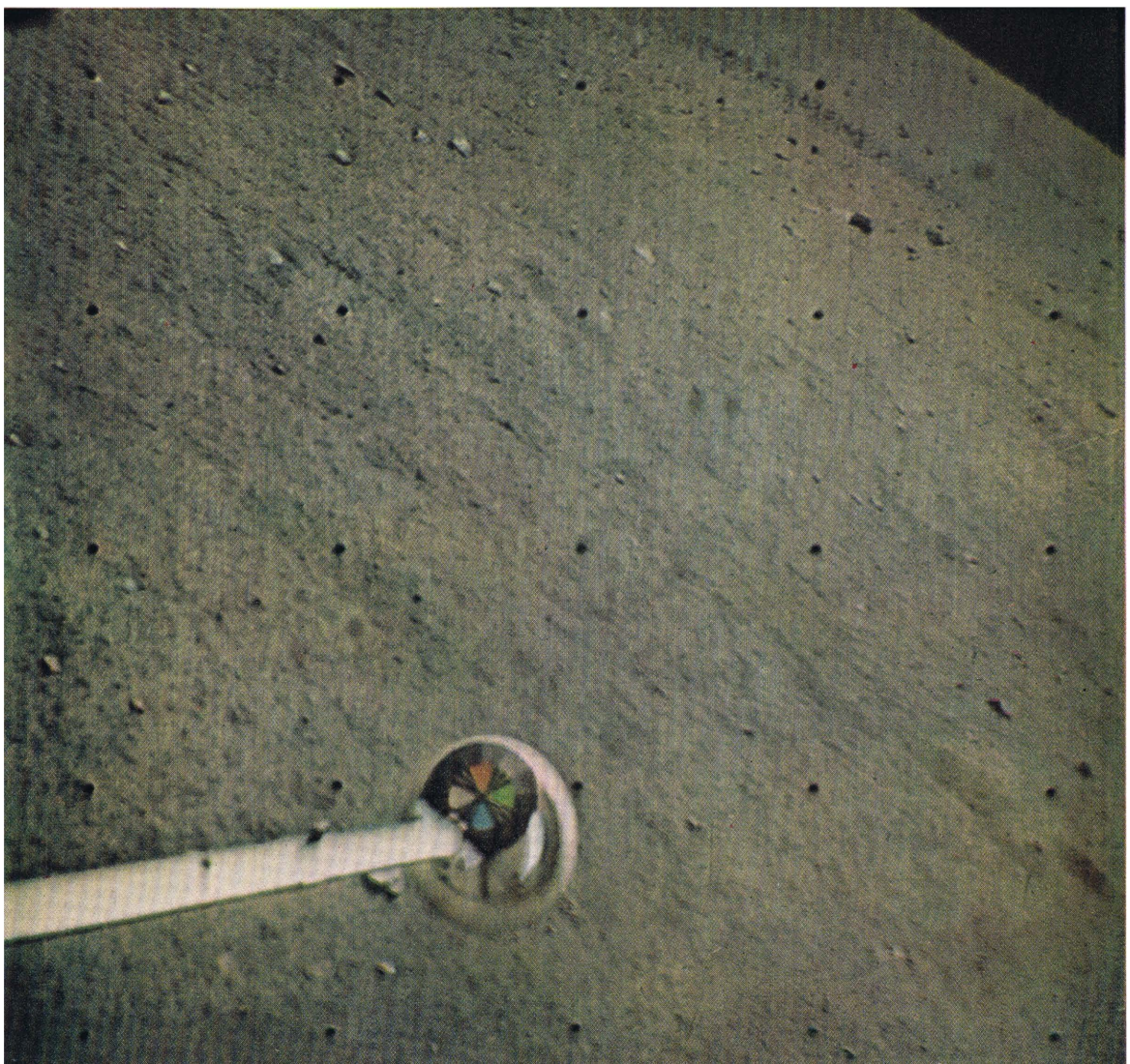
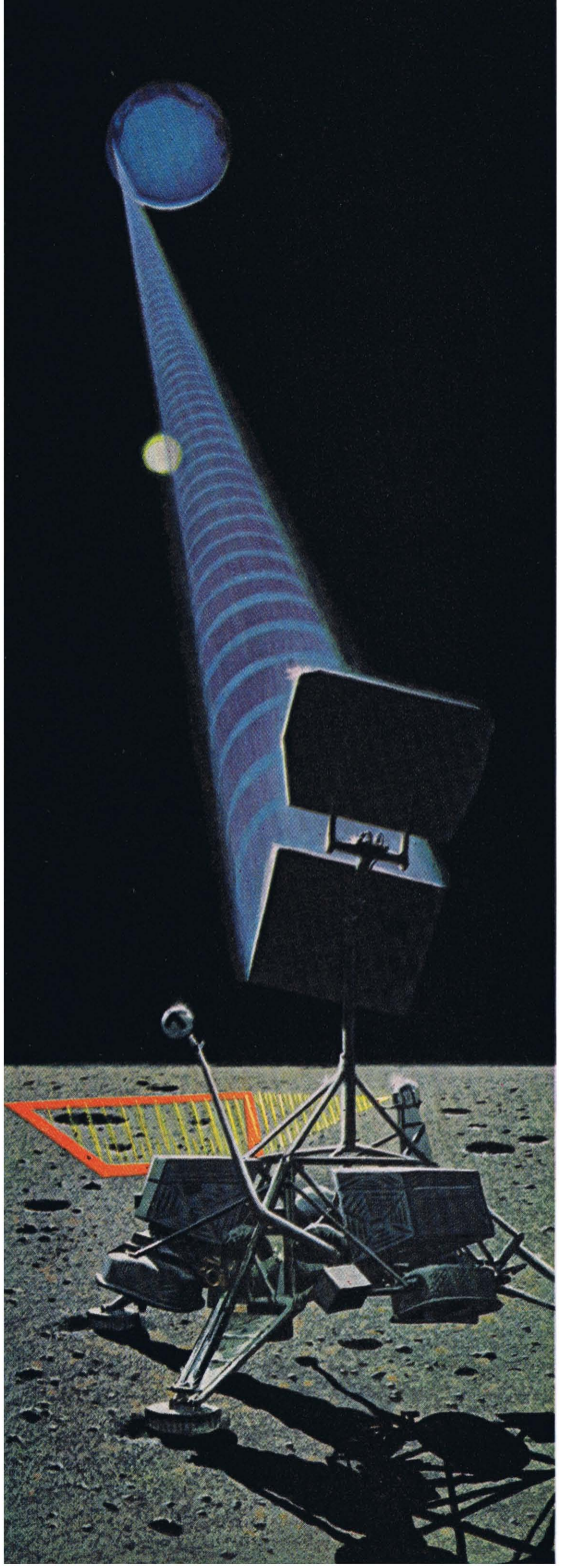




Spraddle-legged robot beams messages to earth

SURVEYOR bridges a quarter-million-mile gulf to present earthlings with a view of the moon almost as clear as if man himself stood there.

Equipment works flawlessly. The solar panel points toward the distant sun (left), converting its rays into electricity to feed the robot. The TV camera stands man-high at right of the mast. (Russia's Luna 9 scanned a nearer horizon from only knee height.) Electronic gear crams two large compartments. Three antennas receive instructions and transmit pictures and data on temperature, voltage, pressure, and switch positions.

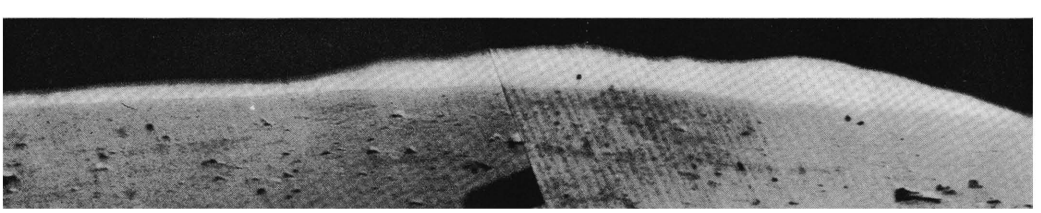
When NASA's deep-space tracking antenna at Goldstone, California, relays an order from JPL, the camera's mirror (page 590) obediently adjusts elevation, swivels left or right, and reflects a section of surface. The camera "reads off" the image, a transmitter beams it to Goldstone in 1.3 seconds, and microwaves flash it to TV consoles at JPL, hub of the project.

The sun wheels slowly overhead, heating the lunar surface to a searing 235° F. at high noon; on signal, Surveyor shades its camera with its square antenna. Then more data and thousands of pictures. In the photograph below, an ancient crater rim at least 10 miles away rises more than 300 feet above the near horizon.

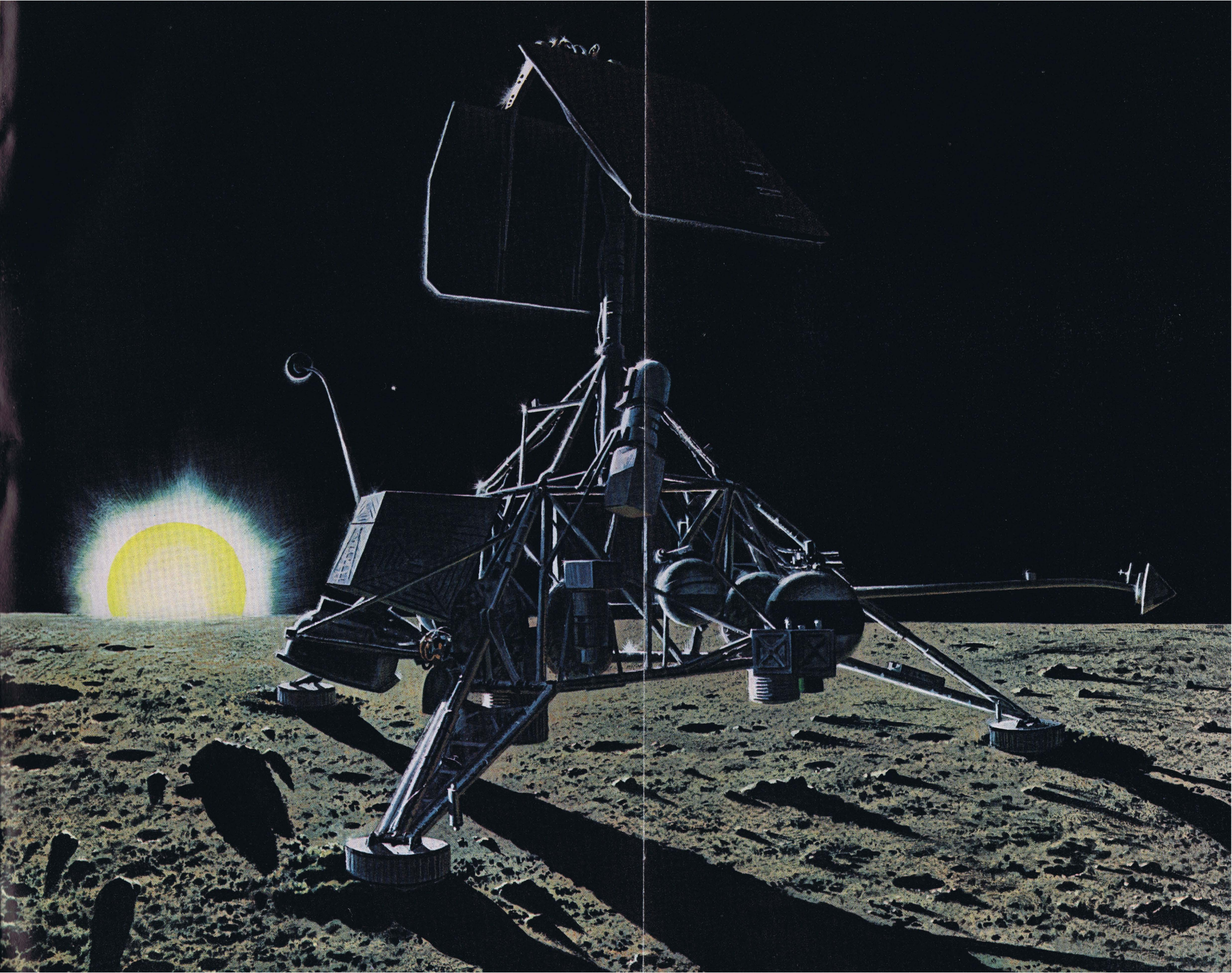
Long shadows creep behind the spacecraft (right), filling small craters and new holes stamped by the shock absorbers when Surveyor settled on the surface during landing (page 588). The solar panel draws its last energy of the day. Temperatures plunge toward the −250° F. mark.

Now Surveyor's earthbound masters point the camera's mirror toward the vanishing sun; earlier its intense glare would have burned the photosensitive vidicon tube. As the sun sets, the corona—its glowing upper atmosphere—flares like a fiery crown; here, the artist portrays it simultaneously with the still-visible solar orb. Half an hour later, Surveyor took a ghostly photograph—a four-minute exposure of the robot's footpad bathed in earthshine, our planet's reflected light.

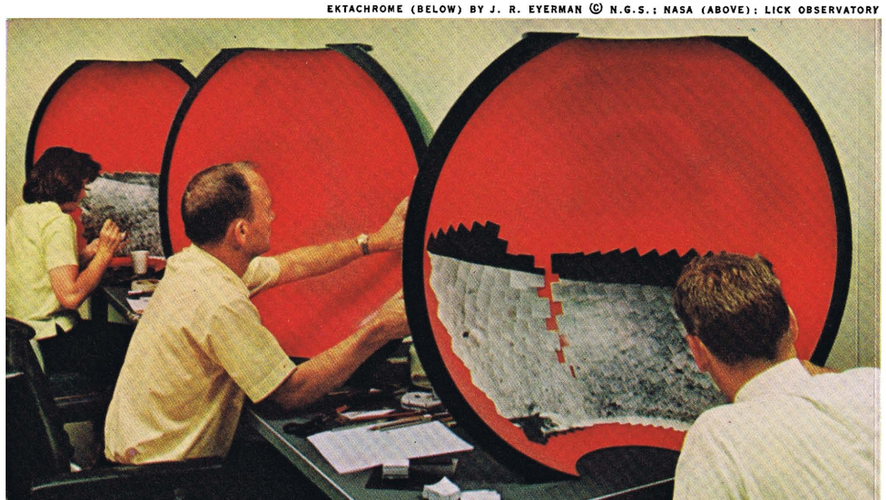
Finally, after executing more than 100,000 earth orders during the two-week-long lunar day, Surveyor settled into sleep for a frigid night equally long. But when day broke, it stirred again to life—and sent hundreds of additional pictures.



PAINTINGS BY DAVIS MELTZER, RESEARCH BY GEORGE W. BEATTY, GEOGRAPHIC ART DIVISION © N.G.S.; NASA PHOTOGRAPH (ABOVE)



EKTACHROME (BELOW) BY J. R. EYERMAN © N.G.S.; NASA (ABOVE); LICK OBSERVATORY



THIS PAGE FOLDS OUT

Pocked Ocean of Storms bares its wounds in a mosaic covering some 100 city blocks. Shallow crater near the horizon lies amid yard-long boulders. Within a few thousand years—mere moments in moon history—eroding hail of space debris may erase holes the size of golf-course divots (foreground). Though micrometeorites may fall like powder on Apollo astronauts, big meteorites crash too infrequently to pose a hazard. Massive impacts such as that which blasted starlike Tycho Crater (right), 850 miles southeast of Surveyor's touchdown (red arrow), spatter debris into space.

Pasting photographs inside hemispheres, technicians produce mosaics with minimum distortion. About 350 "chips" built vista above.

legs spread wide, Surveyor fell the last 13 feet with half the speed of a parachute jumper—approximately 10 feet a second (page 580).

The three-legged robot, weighing about 600 pounds on earth but only about 100 in the moon's lower gravity, bounced slightly, oscillated briefly as its shock absorbers settled, and came to rest undamaged. Its footpads, 12-inch-diameter disks of crushable aluminum honeycomb, dug about an inch into the lunar surface.

At impact, the tubular aluminum legs pivoted to absorb shock, and crushable pads under the "knees" of the legs sank momentarily into the surface. One of the prints shows clearly in the picture at the top of page 588.

What Surveyor saw after it landed was, of course, not totally new. Three Ranger spacecraft had sent back pictures just before crashing into the moon's face.* Russia's Luna 9 landed on the moon last February and took a handful of close-up photographs.

But Surveyor saw with a sharper and clearer eye. And, for the first time, it saw in color. Three separate photographs, taken with orange, green, and blue filters, combined to produce a fairly accurate color representation. As scientists expected, that color seems to be nothing but gray—a plain, neutral gray.

Surveyor had but a single eye, its TV camera. Instead of turning this eye about, it gazed upward at a motor-driven mirror that, on radio command from earth, searched the ground below or scanned the horizon in almost a full circle (painting, page 590).

The camera saw approximately as far as a man's eye would see, since the mirror was about 5½ feet above the surface. The horizon, because of the small diameter and sharp curvature of the moon, lay only about a mile away. On earth the horizon would have been roughly four miles distant.

And what did Surveyor see in the Ocean of Storms? It found itself in a shallow crater some 60 miles across. It had landed on a dark, level, relatively smooth spot. Low-lying hills and mountains of the crater's rim, at least 10 miles distant, poked their crests above the horizon (page 582).

Surveyor Settles an Old Controversy

In every direction stretched an eerie wasteland, scarred with smaller craters from an inch to several hundred feet across and littered with debris. Coarse blocks of rock as wide as three feet and countless smaller fragments lay strewn upon the crater lips and the surrounding areas.

The blocks and fragments represent debris ejected by the constant barrage of meteorites cratering the moon's surface, or rubble thrown out of secondary craters created by the impact of the original flying debris.

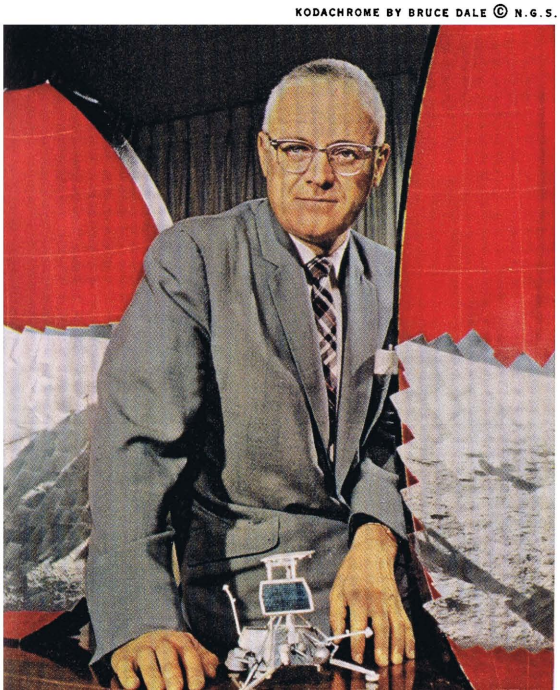
By the time you read this, if all goes well, Surveyor I will have been followed by Surveyor II, next in a series of 10 planned missions. These will examine potential Apollo landing sites and survey other areas.

Lunar Orbiter I also may have flown, whirling round the moon to obtain photographs at altitudes as low as 30 miles and transmit back to earth pictures of potential Apollo and Surveyor landing zones (page 592). But so well did our first lunar soft-lander work that many scientists doubt that its successors will radically change our impression of the surface of the moon's vast "ocean" plains.

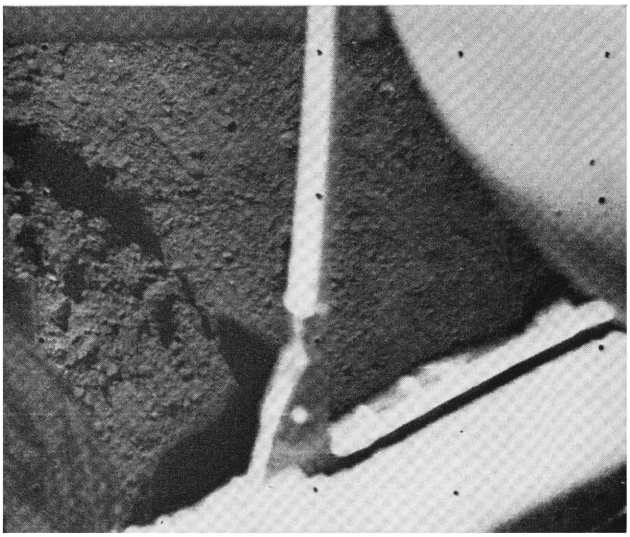
Before Surveyor I's voyage, scientists had engaged in intense speculation and prolonged controversy over the nature of the moon's face. Some argued firmly that the moon was

The author: Space scientist Homer E. Newell directs NASA's unmanned flights as Associate Administrator for Space Science and Applications. Information gleaned by his space scouts—Mariners, Rangers, Surveyors, Lunar Orbiters, and others—paves the way for manned voyages.

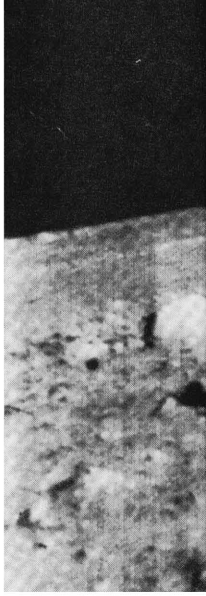
KODACHROME BY BRUCE DALE © N.G.S.

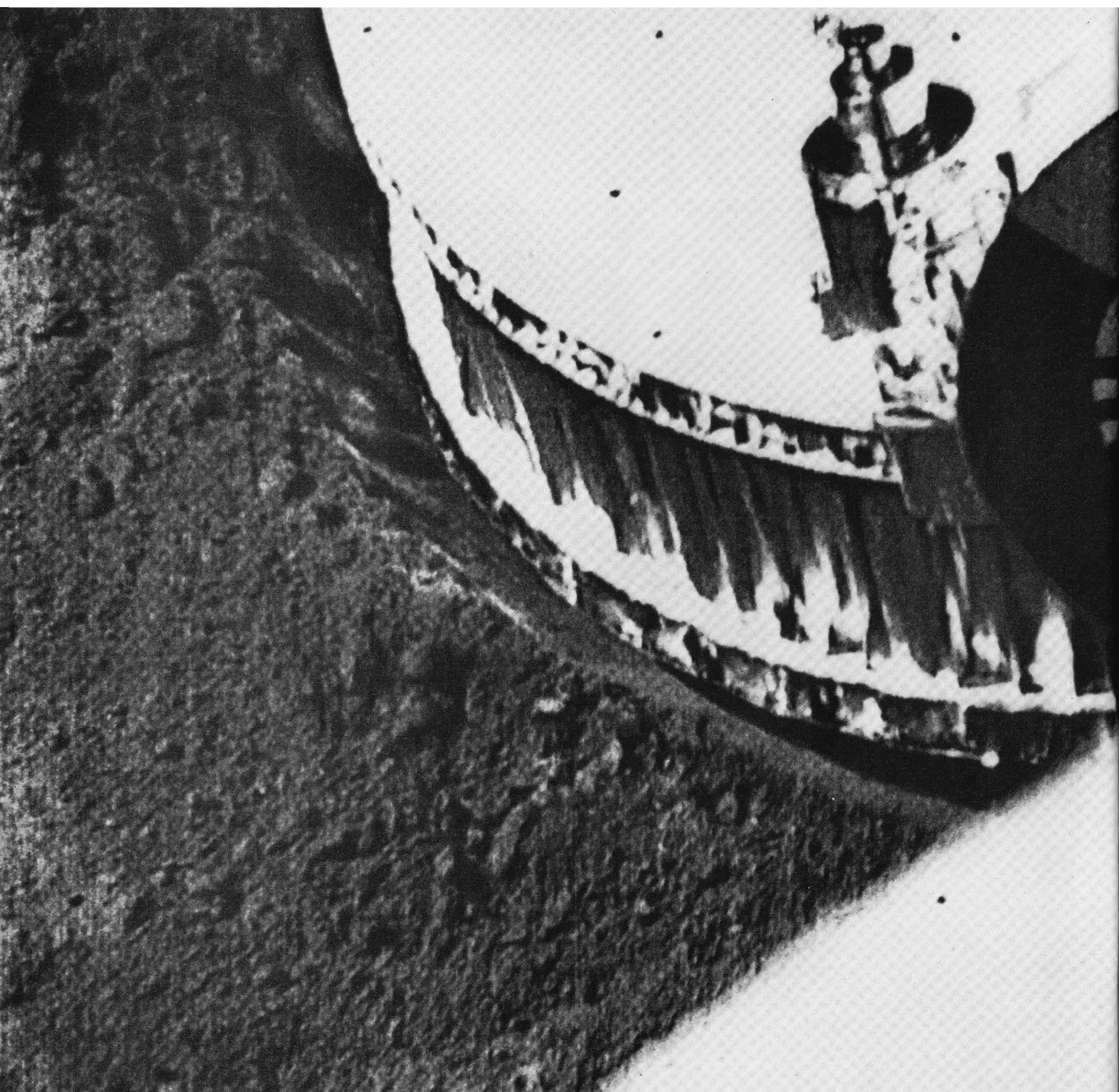


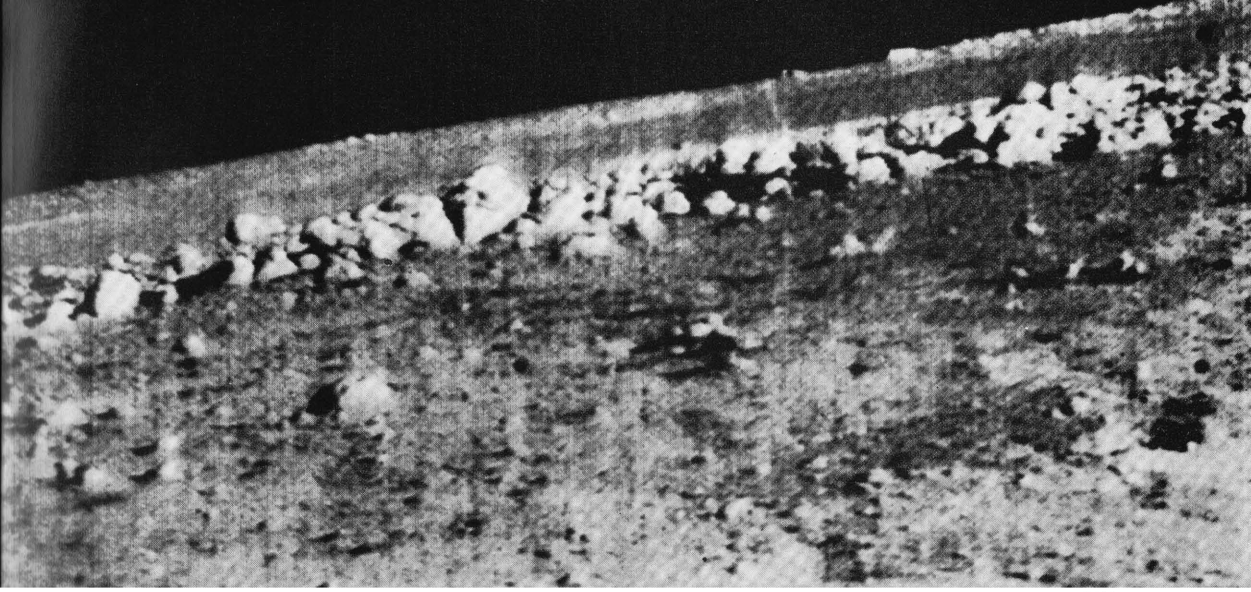
*See "The Moon Close Up," by Eugene M. Shoemaker, NATIONAL GEOGRAPHIC, November, 1964.



"Cookie-cutter picture," analysts call this view showing the imprint of a crushable aluminum shock absorber. Crisp edge of the hole, about 3/4 inch deep, suggests that lunar granules adhere to one another instead of tumbling helter-skelter like grains of sand. But the existence of few clods indicates the cohesiveness is weak—a puzzle to scientists, since many materials in a vacuum, such as the moon's, tend to cling together as if glued.

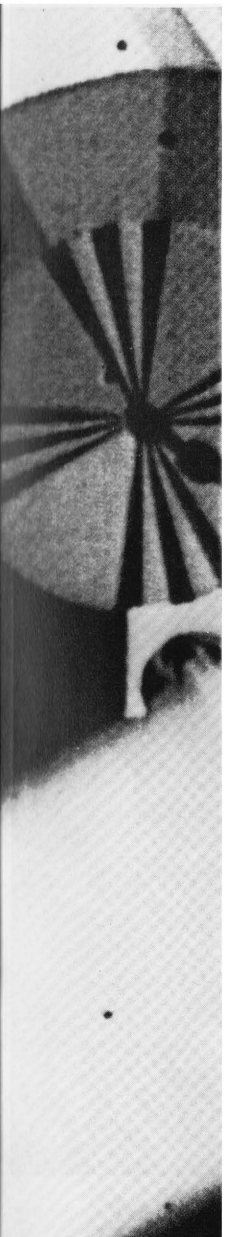




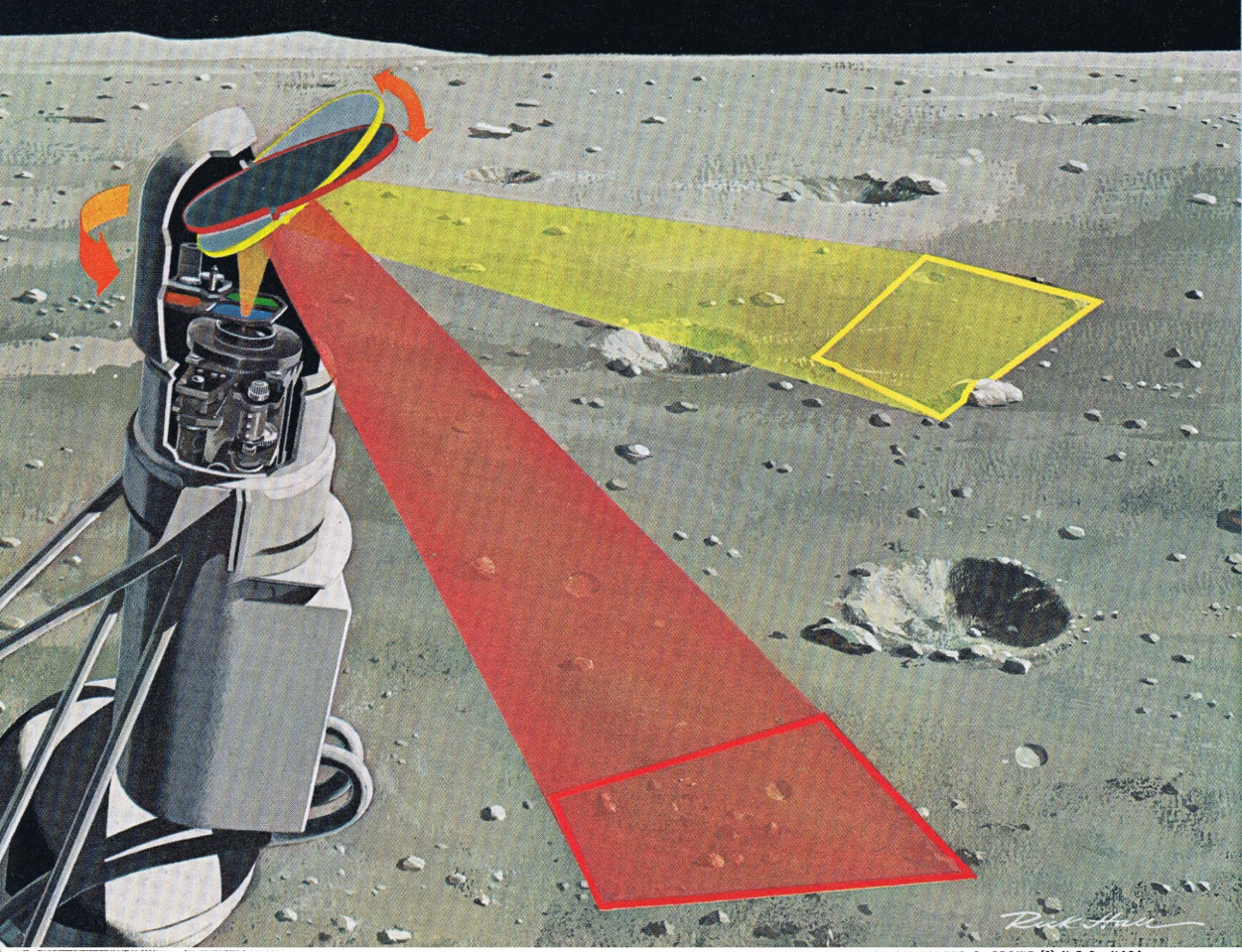


NASA

Waist-high boulders ripped from lunar bedrock rise like a wall, in a view foreshortened by the camera. They litter the rim of an old crater near the horizon. Such blocks could have damaged Surveyor had it dropped on them during the blind landing. Pillow-size rock (below) reveals cavities that indicate it once was molten, either through volcanic action or heat generated by a meteorite's impact. The reconstituted color shows only grays.



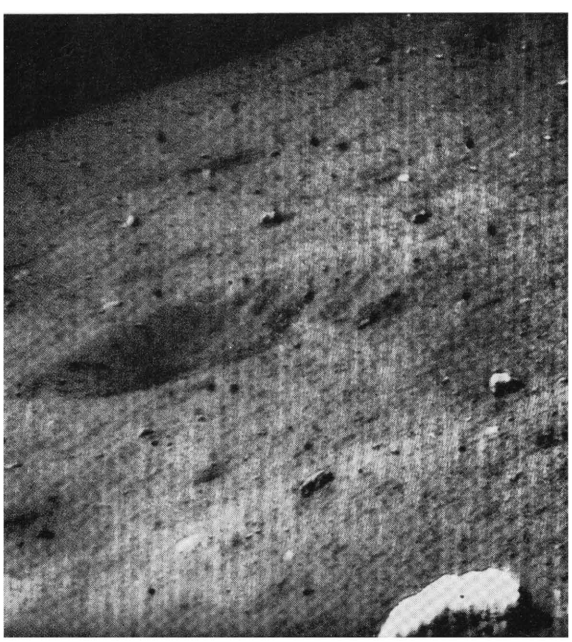
Scuffing the moonscape with an aluminum paw (left), Surveyor peers beneath the surface. Impact of its 13-foot free fall and short bounce gouged the shallow footprint. A close examination indicates the surface to be granular, contradicting theories that a landing on solid rock or smothering dust awaits the first lunar explorers. Particles as small as a pinhole appear in the picture. Future Surveyors may be equipped with a device that can dig some 18 inches into the surface upon command from scientists on earth.

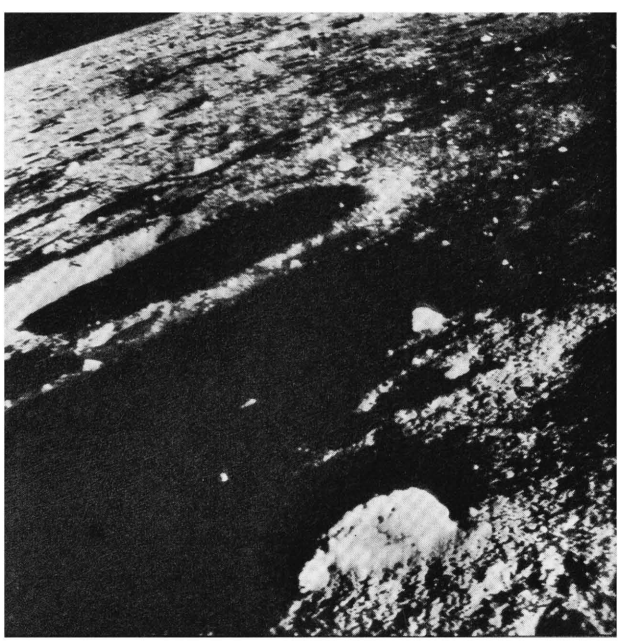


PAINTING BY RICK HALL, RESEARCH BY WALTER Q. CROWE © N.G.S.; NASA

Perched on Surveyor, the TV camera tilts its mirror toward targets equivalent to mosaic chips (pages 585-6). Camera stares rigidly up at the image. To turn its gaze, the upper housing swivels. Cutaway shows zoom lens, color filters, and drive mechanisms.

Shadows heighten lunar features. Rim of a crater (left) appears flush with the surface near high noon, but slanting evening rays show a raised lip (right). Such shadows may reveal danger spots for Apollo astronauts searching for a lunar landing site.





covered with a deep blanket of soft dust. Others maintained just as vigorously that the surface was hard rock. Still others suggested spongy rock, or perhaps a thin covering of dust over rock.

Ranger's pictures did little to settle this controversy, for they were unable to resolve surface details smaller than 18 inches. A good many scientists tended to see in them what they hoped to see.

Surveyor changed all this. Now we know that, at least in one place in the Ocean of Storms, little if any loose dust threatens the Apollo astronauts. At the same time, the moon's surface seems not to consist of hard rock. Instead, scientists who study the Surveyor pictures find a layer of material that looks and behaves much like earthly soil. Judging by the shapes of small craters and the materials thrown up on their rims, we believe this layer may be as much as three feet thick. We think that essentially this same kind of material exists over a very large part of the moon's face, harrowed and worked and broken down by the incessant rain of meteorites.

Dr. Eugene Shoemaker of the U. S. Geological Survey, one of the principal investigators for the Surveyor project, puts it this way:

"The moon's face is certainly not a deep sea of very fine dust. Undoubtedly half the materials are finer than the smallest particles we can see in the Surveyor pictures, and we have measured and counted particles no bigger than a fiftieth of an inch. That is to say, it is like fine sand, or finer, in grain size. But distributed through this are many coarser particles. So it is a very gritty, siltlike material with blocks and chips throughout.

"It is relatively easily disturbed. The effects of the Surveyor footpads landing on its surface are not unlike the effects of walking across a freshly plowed field."

Dust Would Have Fooled Craft's Radar

How can we be so sure about the absence of loose dust? First, by looking at Surveyor's footprint (page 588). The robot's foot has sunk a little way down, just as it would in freshly cultivated soil or in wet beach sand.

Second, the very fact that Surveyor landed so well indicates that there could not be a thick bed of loose dust. Had there been, the landing signal would have penetrated deeply into the dust, and would have deceived the radar about the craft's altitude in the last moments before landing.

There is still another indication. No continuous layer of dust was observed by the television camera on any of the parts of the spacecraft. And obviously, no dust gathered on the camera lens, or our pictures would have been fogged and blurred.

To find out how much weight the lunar surface will support, Dr. Ronald Scott, a soil mechanics expert from the California Institute of Technology, experimented for many hours with a sandbox resembling those used in kindergartens. He varied lighting angles, trying to duplicate lighting effects seen in the moon pictures, to gauge the depth of penetration of the footpads and thus help interpret the properties of the lunar material.

Module's Safety Hinges on Landing Site

Dr. Scott and his colleagues concluded that if the surface material is uniform to a depth of at least a foot, it will support about five pounds to the square inch.

"A man walking on the surface would be in no danger of sinking," says Dr. Scott.

"This determination of the bearing strength of the moon's surface may indeed be the most important of Surveyor's discoveries," adds Benjamin Milwitzky, Surveyor Program Manager at NASA's headquarters.

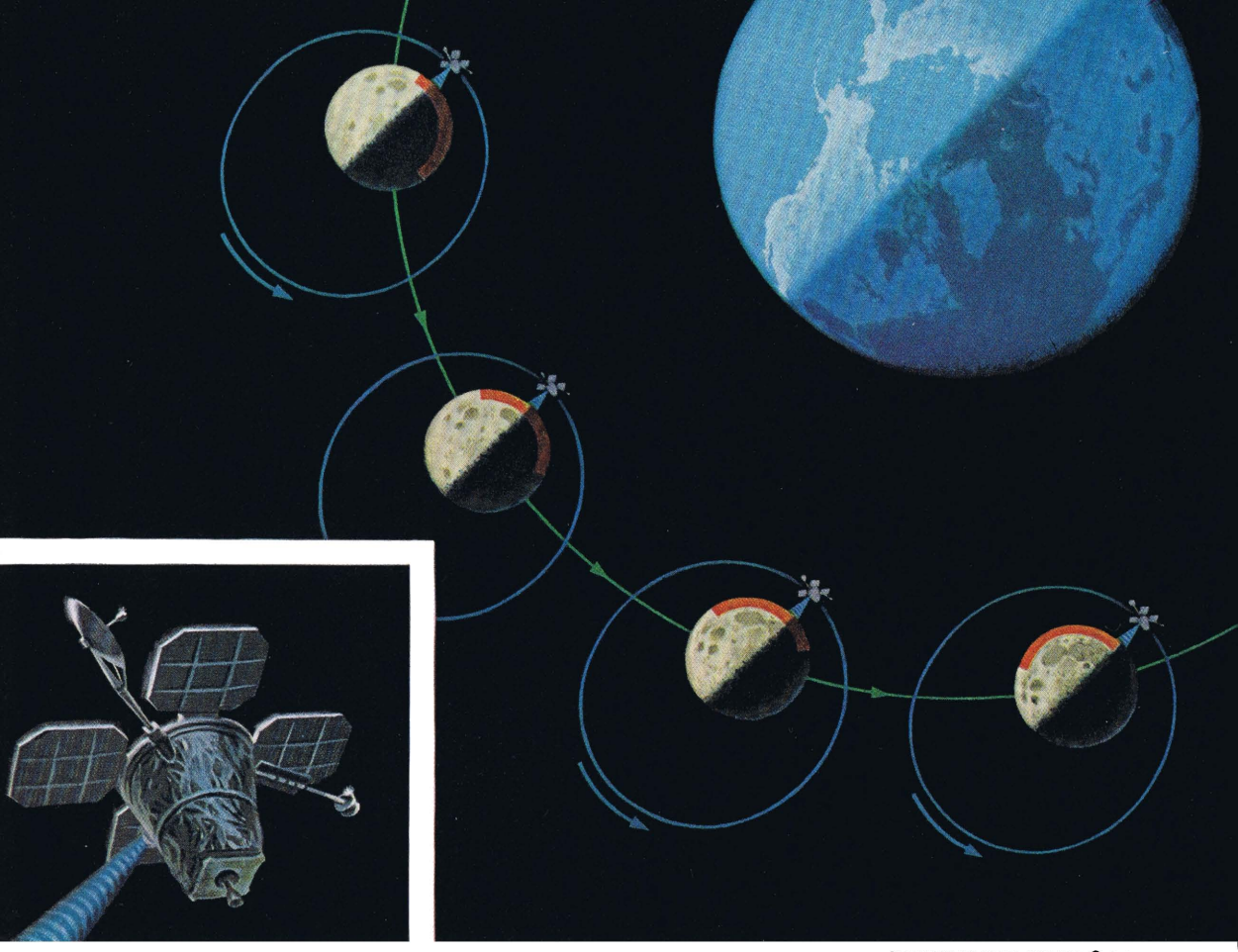
But will the moon support Apollo's LEM, the Lunar Excursion Module, with its two astronauts? This craft will weigh 2,500 moon-pounds compared to Surveyor's skimpy 100; its landing system resembles Surveyor's.*

Yes, we think LEM can land safely if it comes down properly and descends on a site like that on which Surveyor came to rest.

Nevertheless, Surveyor's pictures reveal serious hazards to any spacecraft in the many large rocks that litter even the smooth surfaces of the moon's plains. Dr. Elliot C. Morris of the U. S. Geological Survey estimates that in any area of a hundred square yards, one would expect to find at least one boulder two to three feet across, and many more smaller rocks or fragments.

"In some ways the surface of the moon is definitely more hostile than we thought it might be," says Dr. Robert L. Roderick, Surveyor Program Manager of Hughes Aircraft Company, where the spacecraft was built. "Judging from the Ranger pictures, we did

*For a description of LEM and lunar landing techniques, see "Footprints on the Moon," by Dr. Hugh L. Dryden, late Deputy Administrator of NASA, in NATIONAL GEOGRAPHIC, March, 1964.



DIAGRAMS BY DAVIS MELTZER © N.G.S.

Tracing ellipses around the moon, Lunar Orbiter scouts the Apollo landing belt. Skimming within 30 miles of the surface, the satellite trains its camera near the line dividing light and darkness, where revealing shadows outline treacherous terrain. With solar panels spread (inset), Lunar Orbiter takes overlapping pictures for stereoscopic study. Antennas and rocket engine protrude from aluminized housing that protects the 850-pound craft from the sun's heat.

not expect to find such large rocks or so many of them."

If a spacecraft hit the rock-strewn field shown on pages 588-9, it would not be likely to survive. So it is clear that the astronauts will need to maneuver the LEM to the type of landing spot Surveyor found.

Surveyor tells much about the moon besides the all-important question of its surface. Temperature sensors show what the astronauts may expect in the way of heat and cold. At lunar noon, with the sun's radiation pouring directly down, the moon surface reached 235° F., 23 degrees above the boiling point of water on earth. At sundown heat fled swiftly; the temperature plunged to zero within an hour, and then dropped to about −250° F.

Surveyors to come will add much more to our scientific knowledge. One may carry a scoop to dig a trench for observation of subsurface features to a depth of perhaps 18 inches. Plans call also for an instrument to ascertain the chemical elements in the lunar material; a seismometer to check for moonquakes, to help determine whether the moon is inert or is active internally; and dual cameras to take stereoscopic pictures.

The United States has put its first footprints on the moon. These were made by the aluminum-shod feet of a three-legged robot, to be sure, but they were necessary before man himself could walk there.

SIX-MONTH INDEX AVAILABLE

As one of the privileges of membership in the National Geographic Society, members who bind their GEOGRAPHICS as works of reference will receive upon request an index for each six-month volume. The index to Volume 129 (January-June 1966) is now ready.