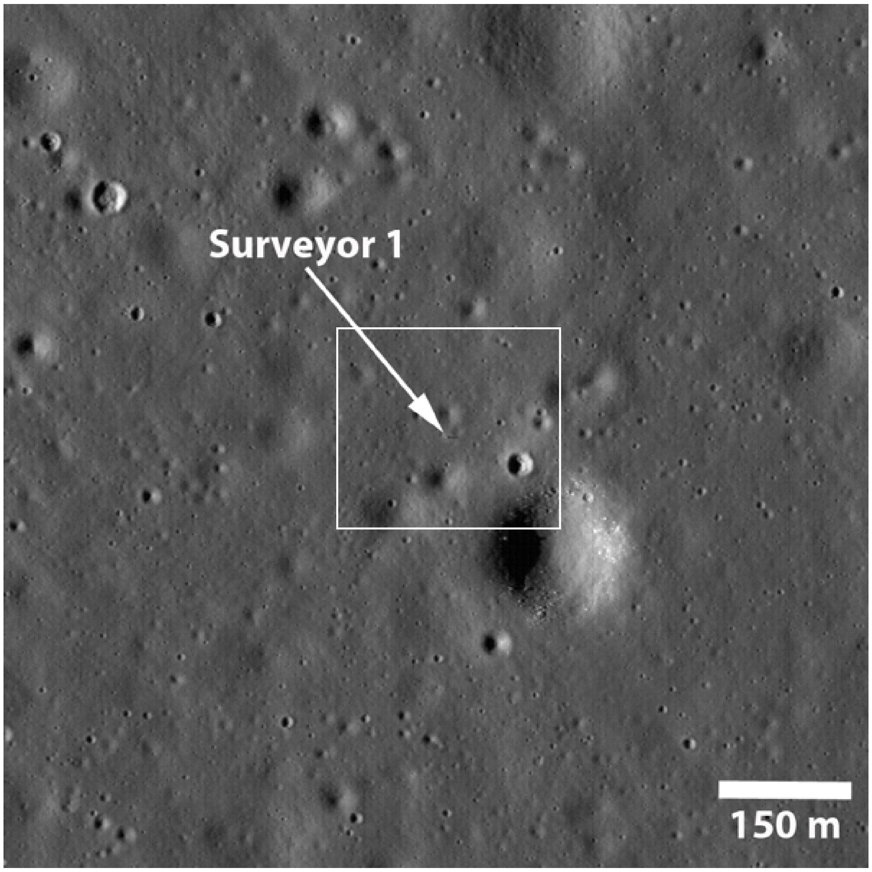
Surveyor I: America's First Moon Landing

by

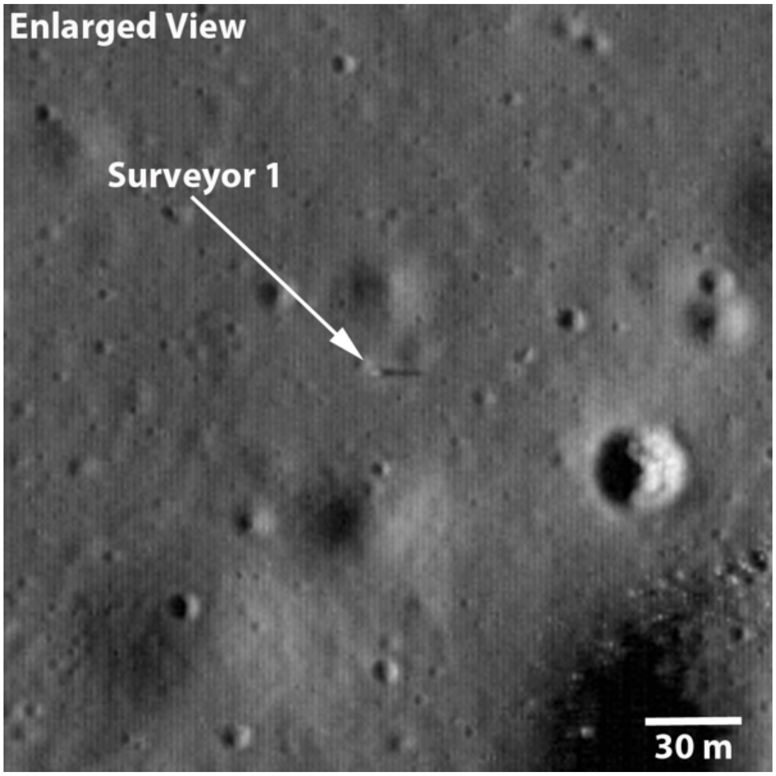
William F. Mellberg

"Project Surveyor, in particular, removed any doubt that it was possible for Americans to land on the Moon and explore its surface."

— Harrison H. Schmitt, Apollo 17 Scientist-Astronaut



Frontispiece: Landing site of the Surveyor 1 spacecraft on June 2, 1966 as seen by the narrow angle camera of the Lunar Reconnaissance Orbiter taken on July 17, 2009 (also see **Fig. 13**). The white square in the upper photo outlines the area of the enlarged view below. The spacecraft is ca. 3.3 m tall and is casting a 15 m shadow to the East. (NASA/LROC/ASU/GSFC photos)



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About the author:

William Mellberg was a marketing and public relations representative with Fokker Aircraft. He is also an aerospace historian, having published many articles on both the development of airplanes and space vehicles in various magazines. He is the author of *Famous Airliners* and *Moon Missions*. He also serves as co-Editor of Harrison H. Schmitt's website: http://americasuncommonsense.com

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A Journey of 250,000 Miles . . .

December 14, 2013. China's Chang'e 3 spacecraft successfully touched down on the Moon at 1311 GMT (2111 Beijing Time). The landing site was in *Mare Imbrium*, the *Sea of Rains*, about 25 miles (40 km) south of the small crater, Laplace F, and roughly 100 miles (160 km) east of its original target in *Sinus Iridum*, the *Bay of Rainbows*. Chang'e 3 made the first lunar landing in more than four decades, the last one being the Soviet Union's Luna-24 spacecraft in 1976. Millions of people across China and around the globe watched the event in real time, aided by commentaries, animations and live images broadcast from the Beijing Aerospace Control Center via CCTV News. As Chang'e 3 began its descent, the appropriately named *Montes Recti* (*Straight Range*) mountains loomed over the lunar horizon. Countless craters filled the foreground. Seven hours after touching down, a six-wheeled rover nicknamed Yutu (Jade Rabbit) descended to the surface from a pair of ramps aboard Chang'e 3. The Chang'e lander was named for the Moon goddess of ancient Chinese mythology. Like the landing craft, Yutu was bedecked with a bright red Chinese flag. This mission marked a great achievement for the People's Republic of China, and a new beginning in the exploration of the Moon and its resources.

June 2, 1966. America's Surveyor I spacecraft successfully touched down on the Moon at 0617 GMT (0217 Eastern Daylight Time). It was 2317 PDT at the Jet Propulsion Laboratory in Pasadena, California, where the mission was being controlled. Surveyor I landed in *Oceanus Procellarum*, the *Ocean of Storms*, approximately 35 miles (57 km) northeast of a relatively small crater named Flamsteed. Surveyor I and Flamsteed were both located inside the 69 mile (112 km) diameter Flamsteed P "ghost" crater, so called because lava flows filled most of the ancient depression a billion years ago, leaving a ring of broken hills which now mark the raised rim of the original crater. As seen from Earth through a backyard telescope, Flamsteed P does, indeed, appear rather ghostly! The landing site was approximately 12 miles (19 km) from the northeast inner wall of the ring. American television viewers stayed up late to follow the live broadcasts from the Jet Propulsion Laboratory as Surveyor I made its final descent to the lunar surface and prepared to transmit its first pictures from the Moon. Europeans watched, too, via the Intelsat I ("Early Bird") communications satellite. Surveyor I's flawless touchdown was a spectacular achievement.

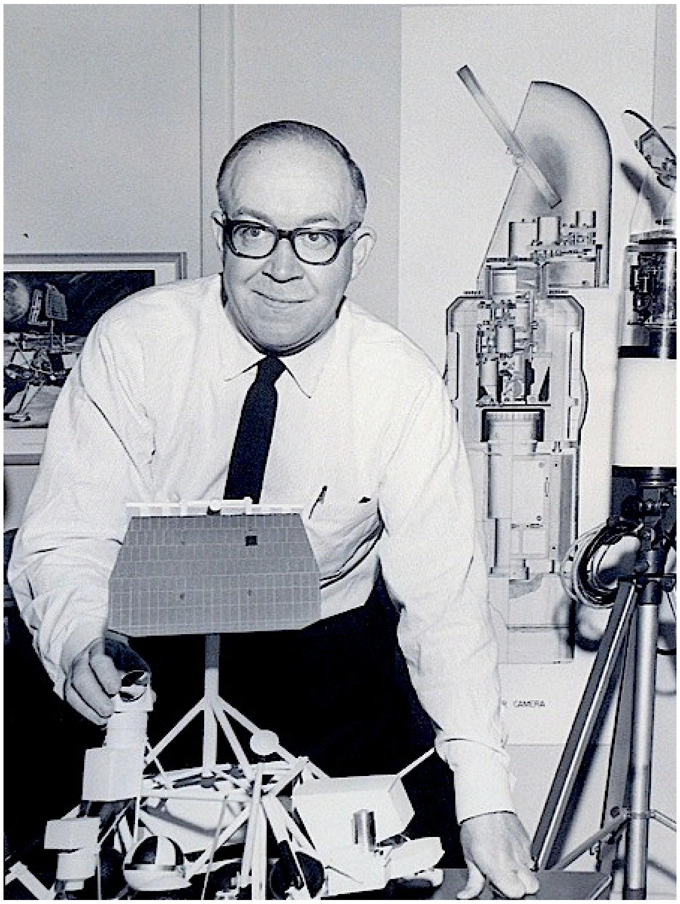

Fig. 1. Frank Mellberg with a model of the Surveyor I spacecraft and a cutaway illustration of its television camera and zoom lens (ca. June 1966).

Nearly half a century ago, I followed America's first Moon landing with the unbridled excitement of a typical 14-year old space enthusiast. My fervor was heightened by the role my father had played in the Surveyor I mission. Frank W. Mellberg was responsible for the design and development of the sophisticated zoom lens system that gave Surveyor its 'eye' on the Moon. He was the Surveyor project manager at the Bell & Howell Company (B&H) in Lincolnwood, Illinois, near Chicago. Bell & Howell was a subcontractor to Hughes Aircraft Company's Space Systems Division (located adjacent to Los Angeles International Airport in El Segundo, California), which had overall responsibility for designing, building and testing the Surveyor spacecraft. Hughes Aircraft Company (HAC), in turn, reported to the Jet Propulsion Laboratory (JPL). And JPL, which is operated by the California Institute of Technology (Caltech), managed Project Surveyor for the National Aeronautics and Space Administration (NASA).

Space Age acronyms can be a bit overwhelming at times, but 'Surveyor' had been a household word in the Mellberg home since the fall of 1961. That is when my father helped win the contract from HAC, on behalf of B&H, to design and build the spacecraft's eyes with a proposal he drafted in a California hotel room. I was only nine years old at the time. But I vividly recall how genuinely enthused Dad was when he returned to Chicago with the most challenging and interesting assignment of his engineering career.

In the Beginning . . .

Project Surveyor had been started at JPL more than a year earlier in the spring of 1960. It was originally envisioned as a scientific probe designed to answer some of the long-standing questions about the origin and nature of the Moon. Project Surveyor would include orbiters and landers, the former intended to map the Moon in unprecedented detail, and the latter designed to investigate its surface. Surveyor's purely scientific role was changed in the Spring of 1961when President Kennedy committed the United States to a manned lunar landing by the end of the decade. Surveyor soon became a supporting player in the Apollo Program, blazing a trail to the Moon for future astronauts. Its new purpose was to test the basic landing techniques that would be employed by Apollo, and to make sure that the lunar surface could support both men and machines. The mapping role was reassigned to NASA's Langley Research Center and became the Lunar Orbiter project.

When Frank Mellberg met with representatives from JPL and Hughes in October 1961, he asked them what the harsh lunar environment was like. He needed to understand the conditions in which Surveyor's 'eyes' would have to operate. He knew that they would be working in a vacuum, and that the glass would be subjected to extremes of heat and cold. But what else was it like on the Moon? Would dust be a problem, for instance?

"At first I thought the people I was talking with were being a bit secretive," Mellberg recalls. "However, I soon realized that nobody really knew what the Moon's surface was like. I was told that some scientists believed the surface might be volcanic rock, rugged and hard. Others said the topsoil would have the consistency of Portland cement, powdery but firm. And a few thought Surveyor might sink into twelve feet of loose dust. The experts were still arguing among themselves about what we could expect to find on the Moon because the biggest telescopes on Earth were unable to resolve any details smaller than a quarter mile (0.4 kilometer) in diameter. But despite this uncertainty, I had to wrap up our proposal for Surveyor's camera lenses in less than four days."

Justin (nicknamed "J.") Rennilson was a JPL scientist who became closely involved with Surveyor's television experiment. He recalls the meeting at which Mellberg presented his proposal for the zoom lens assembly that was to become the 'eye' of the surface camera. "We had a little problem with Hughes to get them to understand that the camera, including all the optical parts, was a scientific instrument and not just for looking at things. There was some competition from firms like Goerz Optical and Fairchild. But I had the opportunity to talk with others at Bell & Howell about their capabilities, including Dr. Arthur Cox [at the time, one of the world's best known optical designers]. And I also knew the reputation the company enjoyed from my graduate study in Berlin." Rennilson was favorably impressed with Mellberg's presentation.

Mellberg's proposal was based, in principle, on zoom lens designs that were already in production for Bell & Howell's commercial movie cameras. B&H won the contract to build Surveyor's zoom lens, as well as a fixed lens for Surveyor's approach camera, which was supposed to televise the vehicle's descent to the Moon. Back in Lincolnwood, Mellberg assembled a small team of engineers, technicians and contract administrators to develop and deliver the first American cameras on the Moon. Project Surveyor would consume their time, talent and attention for most of the next five years.

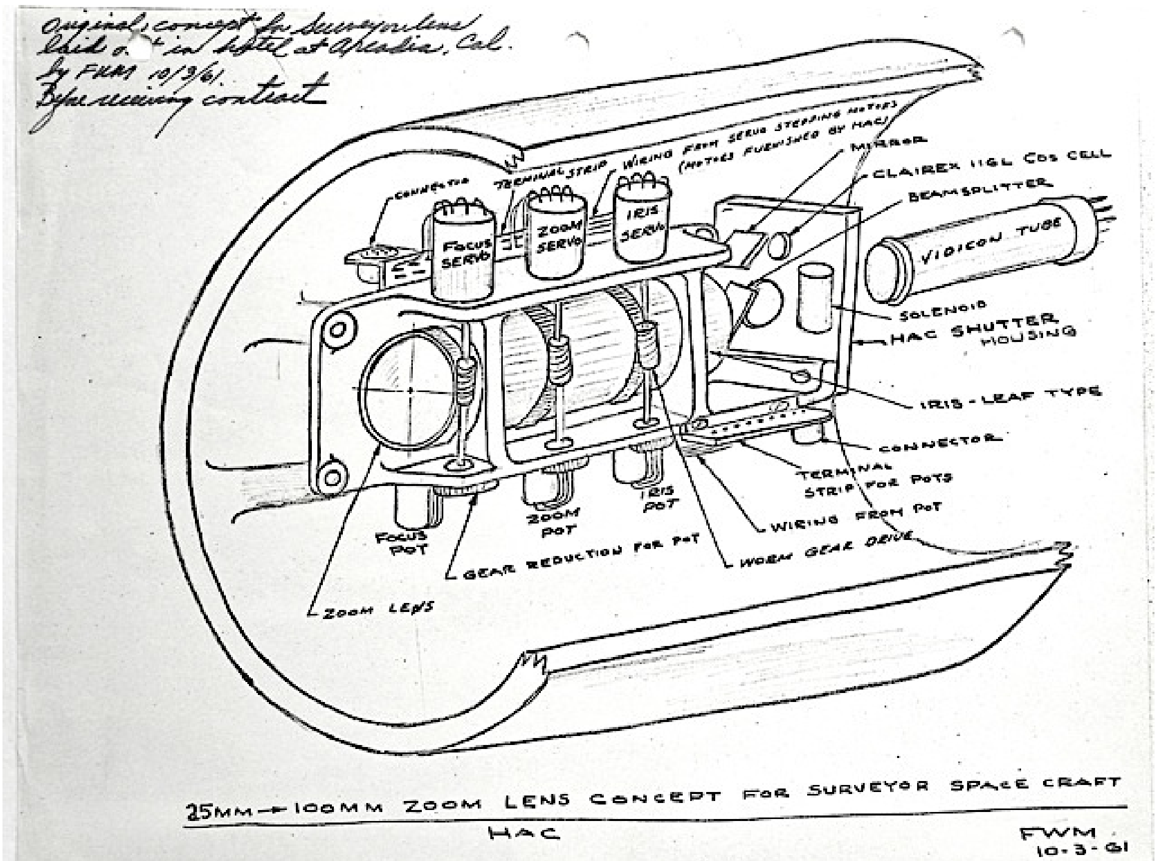

Fig. 2. The proposal for Surveyor's zoom lens that Frank Mellberg sketched in his California hotel room before meeting with representatives of JPL and Hughes Aircraft in October 1961.

I still have a few mementoes from that era, including an artist's concept of Surveyor on the Moon, which used to hang in my father's office, and a glossy Hughes brochure describing the Surveyor spacecraft and its mission.

"In 1964, the Surveyor spacecraft will soft-land a payload of delicate scientific instruments on the Moon," the 1963 brochure confidently stated. "The primary mission of the Surveyor is to provide information vital to the landing of astronauts on the Moon and their safe return to Earth. The scientific data it provides may also make possible a significant breakthrough in the search to understand the origin of the Moon and of the entire Solar System. The first of seven Surveyor spacecraft will be launched from Cape Canaveral by the Atlas-Centaur some time in 1964."

The goals cited in the Hughes publication eventually came to pass. But the dates did not. Countless problems created long delays for the Surveyor spacecraft and its Atlas-Centaur launch vehicle.

Problems, Problems, Problems …

The Hughes booklet and painting both depicted the familiar lines of the Surveyor spacecraft — its 10 foot (3 m) tall triangular frame, its tripod legs and the central mast which supported a solar panel pointed at the Sun for power and a high-gain, planar array antenna pointed at Earth for two-way communications. Attached to the frame were two survey cameras, plus a downward-looking approach camera. Other scientific instruments included "a surface sampler, a soil analysis system and a soil mechanics device." Two thermally controlled equipment compartments were mounted to the spacecraft, as were navigation devices. Three vernier engines, six propellant tanks, a helium tank and two radar dishes were used for the final descent.

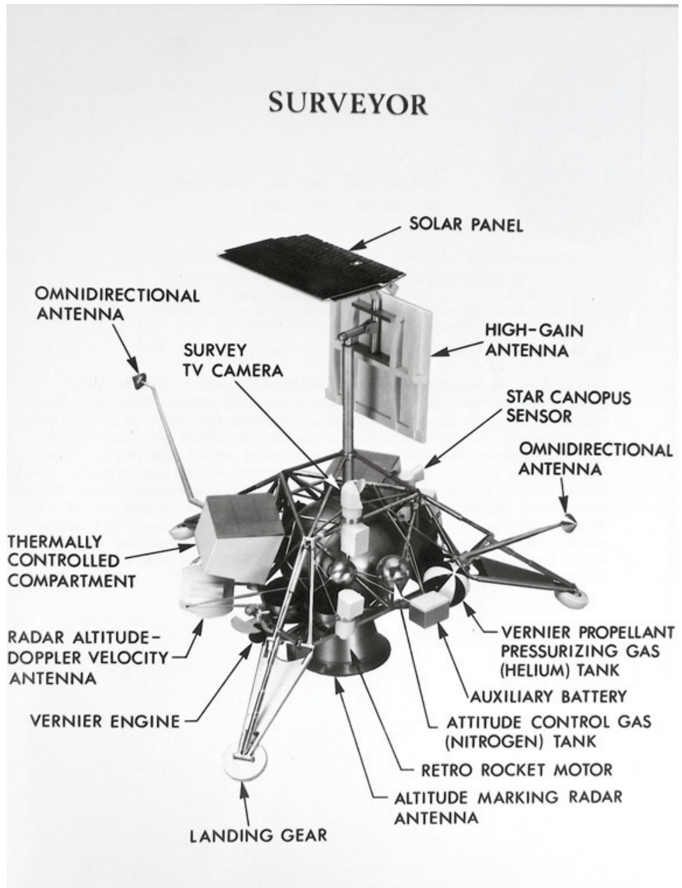

Fig. 3. A model of the Surveyor I spacecraft illustrates its major components. The downward looking Approach TV Camera is the white object below the Survey TV Camera and just above the arrow pointing to the Retro Rocket Motor.

Problems with the Atlas-Centaur rocket reduced the payload that could be launched, which meant some of the scientific instruments had to be deleted from the spacecraft to save weight. By the time Surveyors I and II were flown, a single survey camera was the lone scientific payload carried to the Moon. Surveyors III and IV added soil mechanics and surface samplers (extendable scoopers). Surveyors V and VI were equipped with alpha particle scattering devices (spectrometers) to analyze the soil chemistry. Surveyor VII was equipped with both a surface sampler and an alpha particle scattering instrument. It came the closest to having the capabilities first envisioned for the spacecraft in 1962, thanks to performance improvements and vehicle upgrades in the Atlas-Centaur over time.

The Atlas was a relatively reliable rocket, which carried America's first astronauts into Earth orbit. Dr. Krafft Ehricke designed the high-energy Centaur upper stage for sending unmanned spacecraft to the Moon and beyond. The visionary scientist had been a member of Dr. Wernher von Braun's famous rocket team before joining the Convair Division of General Dynamics that produced the Atlas. Ehricke's Centaur was powered by two Pratt & Whitney RL-10 engines, each producing 15,000 pounds of thrust. They were fueled by liquid hydrogen (LH2). Burned with liquid oxygen (LOX) as an oxidizer,

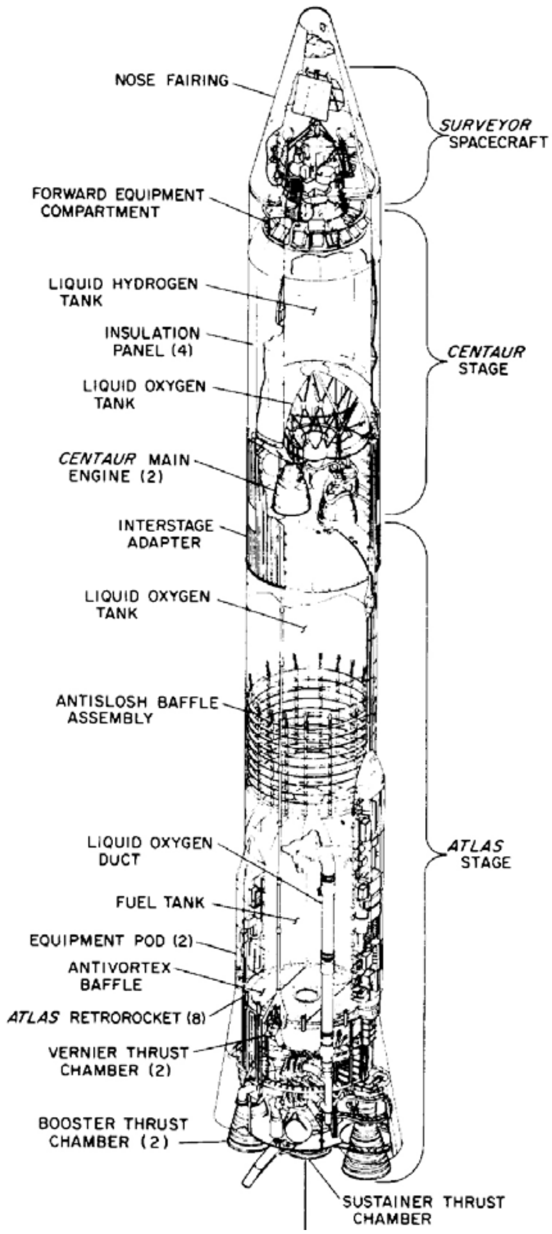

Fig. 4. The Atlas-Centaur rocket with its Surveyor payload.

liquid hydrogen is a most efficient rocket fuel; but its super cold temperature (-423°F/-253°C) presents problems for storage. Centaur's exterior skin had to be equipped with thermal insulation panels to keep its cryogenic fuel in a liquid state. During the first Atlas-Centaur test launch on May 8, 1962, the insulation panels ripped off the vehicle, causing the LH2 inside to expand and rupture the fuel tank. The Atlas-Centaur exploded less than one minute into its flight.

Consequently, the insulation was beefed up, adding weight to the Centaur, which had to be offset by reducing the payload (spacecraft) weight. That was one of the reasons Surveyor's original suite of scientific instruments needed to be pared down. Other changes were also made to eliminate fuel leaks and related problems. The second launch of Atlas-Centaur on November 27, 1963, was the first successful flight of a liquid hydrogen rocket into space, paving the way for Apollo and the upper stages of the Saturn V Moon rocket. But the next three tests were all failures. The fifth vehicle, AC-5, exploded on the launch pad on March 2, 1965. In fact, five of the first seven Atlas-Centaur flights ended in failure, generating both concern at NASA and criticism in Congress.

Surveyor also encountered problems during its protracted development. The spacecraft's soft landing system, including its sophisticated radar and vernier rocket engines, failed during early drop tests at White Sands, New Mexico, in 1964. The vernier engines, which could be throttled in flight, proved to be particularly troublesome.

I still remember a 16mm animated NASA film that my father brought home in 1964. It depicted a typical Surveyor mission from Earth launch to lunar landing. As a 12-year old, my reaction was one of sheer excitement. "That's fantastic!" I exclaimed as the cartoon Surveyor touched down on the Moon. Dad's reaction was less enthusiastic. "It'll never work." And given all of the problems with Atlas-Centaur and Surveyor that year, he was not alone in his pessimism.

Ranger Hits the Moon

JPL did produce some good news in 1964 when the Ranger VII spacecraft crashed into *Mare Nubium*, the *Sea of Clouds*, on the last day of July. The crash was intentional. Before it hit the surface, Ranger VII transmitted thousands of high quality television images recording its lunar plunge, the final frames having 200 times the resolution of the best photographs taken through Earth-based telescopes. Objects as small as a few yards across could be seen, including several large boulders on the floor of a crater the size of a football field. As Ranger VII got closer and and closer to the Moon, its cameras saw more and more craters. Although pocked with depressions of all sizes, the surface appeared to be essentially smooth and flat. Which, as geologist Eugene Shoemaker opined, was good news for Apollo astronauts. It also corresponded with the findings of French astronomer Audouin Dollfus whose telescopic measurements of the Moon's polarization properties indicated that the surface was comprised of fine-grained particles.

The Ranger VII mission marked the beginning of a new development in lunar exploration — close-up investigation of the Moon. It followed a string of six earlier failures. In honor of Ranger VII's stunning success, the region it imaged in so much detail was renamed *Mare Cognitum*, the *Known Sea*.

Two more Ranger spacecraft captured high-resolution pictures of the lunar surface the following year. On February 20, 1965, Ranger VIII crashed into *Mare Tranquillitatis*, the *Sea of Tranquility*, near the future landing sites of Surveyor V and Apollo 11. The landscape looked very similar to that seen by its predecessor. Ranger IX was sent into the large crater Alphonsus on March 24, 1965. As it plunged toward the Moon, its images were carried in real time over network television. For the first time, viewers saw the words "Live from the Moon" at the bottom of their screens. Alphonsus was chosen as the target because some scientists believed it might be the site of recent volcanic activity. Soviet astronomer Nikolai Kozyrev reported seeing a reddish glow emanating from its central peak in 1958. Ranger IX's images gave no hint of such emissions. However, lunar scientist Paul Spudis notes that they did show "dark-halo craters aligned along cracks on the floor of Alphonsus — our first close-up views of lunar cinder cone volcanoes."

"The Ranger photographs are a mirror in which every selenologist (lunar scientist) can see his own theory," opined Cornell astronomer Thomas Gold. He was the leading advocate of the dust theory. Dr. Gold believed the lunar surface was covered with a deep layer of dust in which an astronaut or spacecraft would quickly sink and forever disappear.

Eugene Shoemaker, Chief of the U.S. Geological Survey's Astrogeology Branch, had a very different interpretation. As Dr. Spudis, Senior Staff Scientist at the Lunar and Planetary Institute, now explains, "Even before Ranger, Shoemaker recognized that the regolith (the Moon's topsoil) had been created over time by micrometeorites grinding the surface into a fine powder overlying bedrock." He believed the surface would support Apollo astronauts.

In fact, USGS geologist (and future Apollo 17 moonwalker) Harrison Schmitt used a close-up Ranger photograph to simulate a plan for lunar exploration. But Shoemaker, who played a key role in the television experiments for both Ranger and Surveyor, acknowledged that the only way to resolve the remaining mysteries of the Moon was to actually land there.

Surveyor Comes Together

While the Ranger spacecraft were providing the first close-up views of the Moon, Frank Mellberg and his team at Bell & Howell were busy developing the camera lenses for the Surveyor spacecraft. Surveyor I would carry two television cameras.

"The approach camera was designed to take pictures at the rate of one every three seconds during the vehicle's descent to the lunar surface," Mellberg explains. "It was equipped with a 100mm f/4.0 fixed focus lens and an adjustable iris diaphragm. It was a relatively simple design both optically and mechanically." The images transmitted by the approach camera would help pinpoint Surveyor's landing site.

"The survey camera," Mellberg continues, "was designed to scan the surface after touchdown, providing detailed images of lunar rocks, craters and soil. The camera axis was mounted to the spacecraft pointed vertically and contained a gimbal mounted mirror which could look 45 degrees above the horizon, 40 degrees below it and nearly 360 degrees around the landing site. A rotating filter wheel beneath the mirror enabled the camera to take color images of the surface. Under the filter wheel was the f/4.0 variable focal length zoom lens that provided wide-angle views at its 25mm setting and telephoto pictures at the 100mm setting. It could focus on objects from four feet to infinity. The mechanically operated zoom lens contained twelve glass elements, plus a beamsplitter and a condenser element. The beamsplitter diverted a small portion of incoming light to a photodiode, which operated an automatic shutter so that the vidicon tube would not be accidentally pointed at the Sun. The shutter was located beneath the beamsplitter. The vidicon tube and its related electronic components and connectors (produced by another subcontractor) were at the bottom of the survey camera."

Stepping motors controlled the spur gears that changed the settings of the zoom lens. During a typical mission, those parts would be cycled thousands of times. "And those moving parts were our biggest challenge," Mellberg remembers. "Getting things to operate in the hostile lunar environment was not easy. Not only did the cameras and spacecraft have to survive the shock and vibration associated with the launch of the Atlas-Centaur; they also had to operate on the Moon where temperatures ranged from +250 °F to -300 °F. Moreover, they had to work in a vacuum. Normal lubricants such as oil and grease cannot be used in those conditions. So we used a dry lubricant called Lubeco 905. Environmental testing of the zoom lens was done in Chicago at Inland Testing Labs."

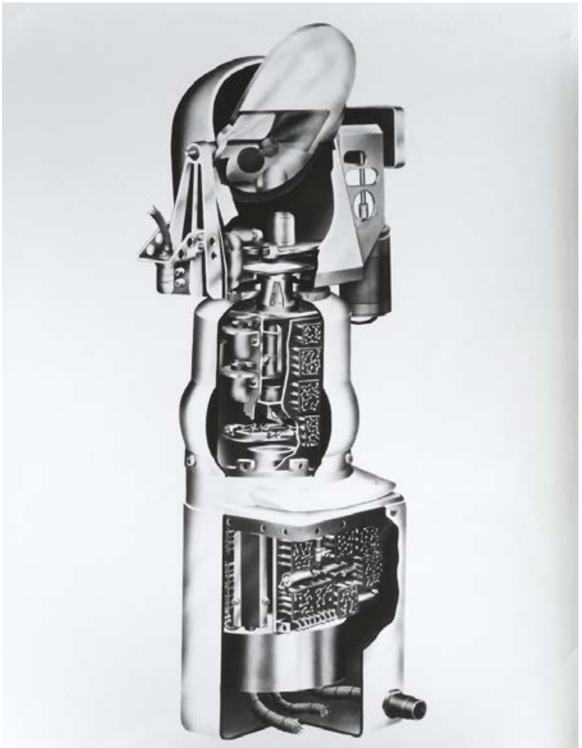

Fig. 5. This cutaway illustration shows the Surveyor television camera. The zoom lens is in the center section with the color filter wheel, tilting mirror and rotating hood assembly above it.

Mellberg recounts the importance of carefully monitoring the movement of the zoom lens parts while the survey camera was operating on the Moon. “Knowing how many times specific gears rotated enabled us to determine how far objects were from the lens, which further enabled us to measure their size. That’s how the scientists were able to determine the size and distance of the rocks and craters seen in Surveyor’s images.”As JPL’s Justin Rennilson had pointed out early on, the survey camera was “a scientific instrument.”

“Along those lines,” Mellberg adds, “a technician from Bell & Howell’s optical lab identified a last-minute change that was needed for the zoom lens going to the Moon on Surveyor I. Bob Nelson recognized that all of our testing had been done on Earth with the lens ‘looking’ through air. But in the vacuum environment found on the Moon, the lens would be just a tad out of focus. None of the specs had referred to this situation. So we had to make a small adjustment to the lens before it flew — setting it slightly out of focus here on Earth so that it would be in sharp focus on the Moon.”

By the fall of 1965, the prospects for Project Surveyor were finally looking up despite a long series of frustrating failures and costly delays. The camera lenses were performing as promised in Illinois. A Surveyor test vehicle made a perfect descent and landing in New Mexico. The sixth Atlas-Centaur was successfully launched in Florida. And the first lunar bound spacecraft (SC-1) was coming together in California. It appeared as if the United States was going to make the first Moon landing in 1966.

The Soviets Get There First

February 3, 1966. After eleven previous attempts starting in 1963, not all of which were publicly acknowledged at the time, the Soviet Union’s Luna-9 spacecraft successfully touched down on the Moon at 1845 GMT (2145 Moscow Time). The landing site was in *Oceanus Procellarum*, the *Ocean of Storms*, about 60 miles (100 km) northeast of the crater Cavalerius, and due west of the crater Reiner.

Luna-9 had been launched from the Baikonur Cosmodrome in Kazakhstan on the last day of January. As the spacecraft approached the Moon, its radar system triggered a retrorocket at an altitude of approximately 45 miles (75 km). In 48 seconds, Luna-9's speed was reduced from 5,800 mph (9,360 kmh) to less than 13.6 mph (22 kmh) at touchdown.

Alexander Gurshstein worked on the Luna project as a young scientist in Sergei Korolev's OKB-1 design bureau (today's RSC "Energia"). He refutes the term "semi-soft" that has been used for the past half century in so many Western descriptions of Luna-9's landing, noting that its touchdown speed was just slightly greater than Surveyor's. But Gurshstein acknowledges that unlike Surveyor, which was similar in its overall design to the Apollo Lunar Module, a hypothetical mini-cosmonaut probably could not have survived Luna-9's landing method.

Perched atop the Luna-9 spacecraft was an egg-shaped Automatic Lunar Station (ALS). Below the spacecraft was a 13-foot (4 meter) probe. Shortly before touchdown, two balloons inflated on either side of the ALS, creating a large, helium-filled ball. When a sensor at the tip of the probe touched the lunar surface, the ball was ejected up and away from the spacecraft just before it hit the Moon. The ball bounced briefly along the ground, and the balloons were discarded as it rolled to a stop. The bottom of the 220-pound (100 kg) station was weighted so that it would come to rest right-side up.

A few minutes later, four petal antennae opened like a flower at the top of the lander, exposing a facsimile camera which soon began taking the first of three panoramic pictures that Luna-9 transmitted of the surrounding terrain. The turret-shaped camera could resolve details as small as two millimeters at a distance of five feet (1.5 meter). A small mirror inside the turret scanned the scene vertically. After each scan, the turret rotated slightly horizontally. Over a period of 100 minutes, the camera produced a complete 360-degree panorama. Three such panoramas were produced in the three days that the station's batteries lasted. Mounted just two feet (60 cm) above the ground, the camera's view of the horizon was less than one mile (1.5 km) away. (Surveyor's camera was mounted near eye level and would see a bit farther.)

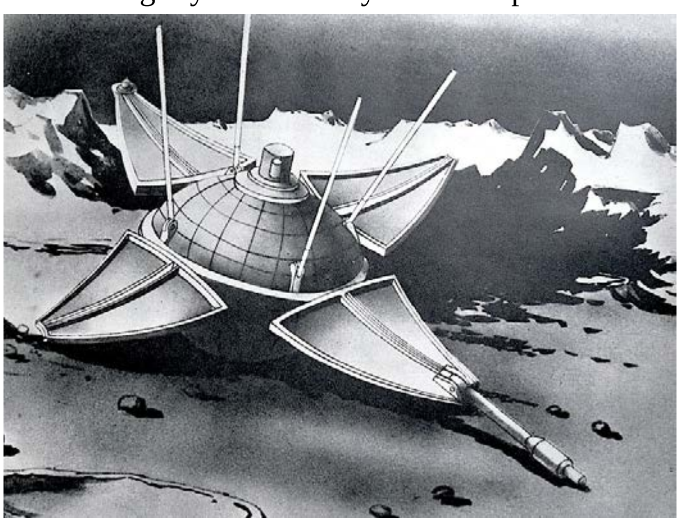

Fig. 6. This artist's depiction of the Soviet Union's Luna-9 lander was released by the official Novosti Press Agency shortly after its successful touchdown on the Moon.

Luna-9's historic photographs, the first ones taken from the lunar surface, were transmitted to the Soviet deep space tracking station in the Crimea. They revealed an interesting landscape.

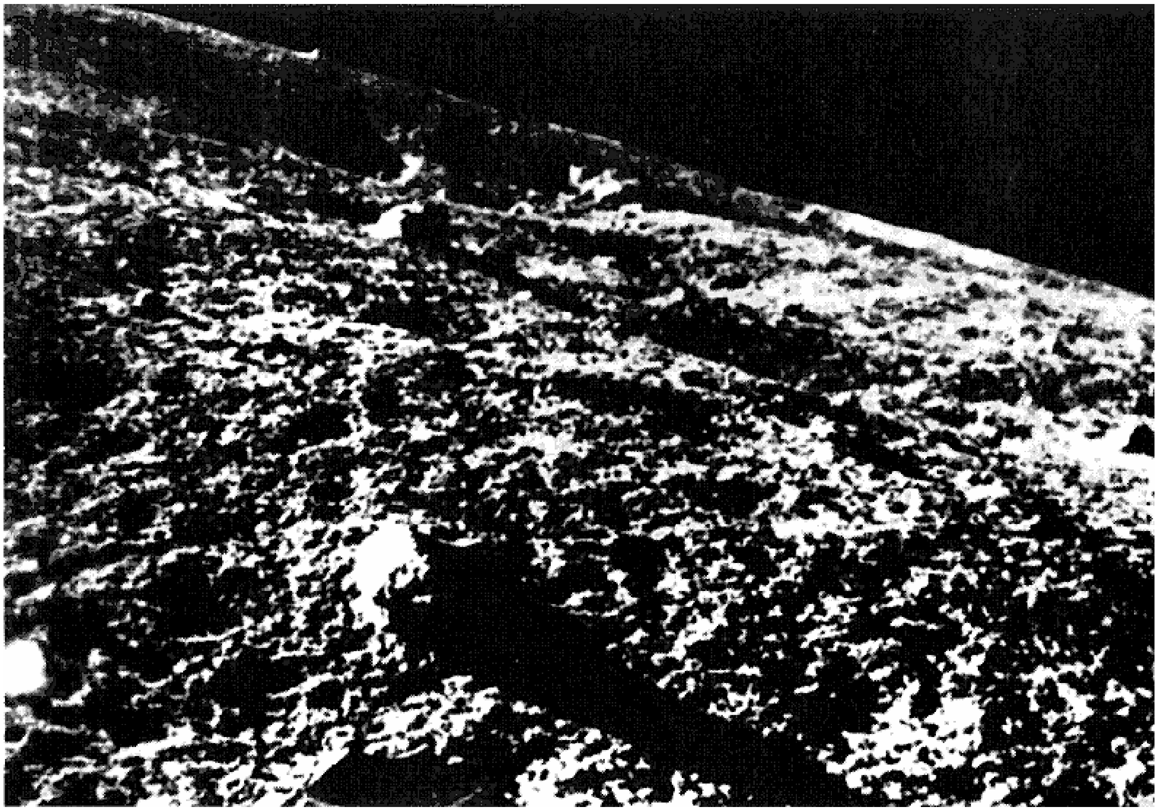

Fig. 7. A portion of Luna-9's historic first panoramic image from the lunar surface.

The first panorama was taken at a low Sun angle (7 degrees), so the shadows were long and the contrast was sharp. The terrain was generally flat. Rocks of various sizes were scattered about the surface — including one rounded example about six inches (15 cm) across directly in front of the station. In the distance, shallow craters of various diameters were visible — resembling the ones seen in the final images taken by each Ranger spacecraft. Luna-9 appeared clean, and there were no signs of dust on the station or its camera. Additional details could be seen in the second and third panoramas, taken when the Sun angle was 14 and 27 degrees, respectively.

As with Ranger's images, different scientists offered various interpretations of Luna's pictures. But most of them agreed with the rather obvious conclusion that the lunar surface could bear the weight of an astronaut or cosmonaut.

Luna-9 was another important step on the road to the Moon.

Surveyor I Reaches the Moon

Luna-9 stole a bit of Surveyor's thunder in the epic Race to the Moon. But it did not slow Surveyor's progress. The March 18, 1966, issue of 'Lunar Landmarks,' the Hughes Surveyor project newsletter, reported that SC-1 had completed its combined system test with the AC-10 Atlas-Centaur launch vehicle and was at Cape Kennedy undergoing final preparations for its lunar journey.

That journey began from Complex 36-A with a perfect launch at 1441 GMT (1041 EDT) on May 30, 1966. It was the eighth Atlas-Centaur launch, but the vehicles were flown out of sequence with AC-10 being used for the Surveyor I mission. The spacecraft was injected into a direct ascent toward the Moon without the use of a parking orbit around Earth. The Sun and the bright star Canopus were used to orient Surveyor in space. Sixteen hours into the flight, a midcourse correction maneuver was executed, setting the stage for Surveyor's lunar arrival inside the Flamsteed P ghost ring crater two days later. Communications with the Space Flight Operations Facility ("mission control") at JPL in Pasadena were maintained via the Deep Space Network and three tracking stations located equidistant around the globe. Giant antennas in Goldstone, California; Johannesburg, South Africa; and Tidbinbilla, Australia, provided round-the-clock contact with the spacecraft. Telemetry indicated that one of Surveyor's two omni-directional antennas had not extended, but it was not a significant problem. Signals were still being received by and transmitted from "omni A."

Unfortunately, engineers had already determined that there would not be enough radio bandwidth to use Surveyor I's approach camera. The camera was carried to the Moon. But it was not turned on in flight.

After a 63-hour trip, Surveyor began its terminal descent. An altitude marking radar unit, positioned inside the nozzle of the main retrorocket, initiated the landing process approximately 60 miles (100 km) above the lunar surface. An automatic timer triggered the ignition of the three liquid fuel throttleable vernier engines which stabilized Surveyor, followed by the firing of the solid fuel, main retrorocket. The marking radar was ejected from the retrorocket as it began its 40-second burn. In less than a minute, Surveyor's speed was reduced from 6,100 mph (9,900 kmh) to just 250 mph (400 kmh). The big, ball-shaped retrorocket and its heavy steel casing, which had filled the empty space inside the vehicle's triangular frame, was dropped at 30,000 feet (9,150 meters) so as to reduce Surveyor I's touchdown weight to 620 pounds (280 kg). It had weighed 2,194 pounds (995 kg) at launch. The vernier engines took over the job of further slowing the spacecraft for its final descent to the Moon.

It was a dramatic sequence of events, all of which were monitored anxiously by engineers at JPL's Space Flight Operations Facility (SFOF) and followed closely by television viewers around the globe — including Frank Mellberg and his wife and two sons in suburban Chicago. JPL's Von Karman Auditorium was packed with journalists. Roy Neal of NBC News, and George Herman and Terry Drinkwater from CBS News, were among the television reporters covering the story. They showed viewers animated depictions of Surveyor's descent, explained Surveyor's design using models and a full-size replica of the spacecraft, and talked with scientists about the Moon, including Nobel Laureate and lunar expert, Dr. Harold Urey.

Dr. Albert Hibbs, a Caltech scientist and the legendary "Voice of JPL," provided a running commentary of Surveyor I's exciting final approach to the Moon as the spacecraft continually reported its status . . .

“The retrorocket is now firing.”

“We are now at 30,000 feet. Retro burnout is confirmed.”

“Four hundred feet per second vertical velocity . . . 28,000 feet.”

“Four hundred feet per second . . . 12,000 feet.”

“Two hundred feet per second . . . 8,000 feet.”

George Herman of CBS interrupted Hibbs’s litany with his own enthusiastic comment:

“An extraordinary moment. What may be in the making here ... one of the most surprising and dramatic successes of the United States space program.”

“Four thousand feet and stable.”

“And stable,” Herman repeated. **“That was a key word.”**

Surveyor I’s automatic landing system was doing its job. The radar altimeter, Doppler velocity sensors and vernier engines were maintaining level flight and slowing the spacecraft as it neared the surface.

“One thousand foot mark,” Al Hibbs calmly reported.

“Thirty eight seconds to go,” Herman injected, hardly containing his excitement.

At the Mellberg home, all eyes were glued to our television set. Not a word was spoken as we followed those final seconds. It was well past 1:00 a.m., and I had to be in my 8^{th} Grade classroom later that same morning. But I would not have missed this moment for anything.

“Four hundred feet.” Hibbs continued. **“Two hundred feet.”**

“One hundred feet . . . thirteen feet per second.”

And moments later . . .

“Touchdown!”

Surveyor I had successfully completed America’s first Moon landing!

Cheers were heard at JPL. Engineers, scientists, managers and journalists all broke into spontaneous applause as Surveyor I reported that all was well on the Moon. In fact, the landing had apparently jolted omni A into its properly extended position. Surveyor’s vernier engines had cut off as planned at 13 feet (4 meters) above the surface. The

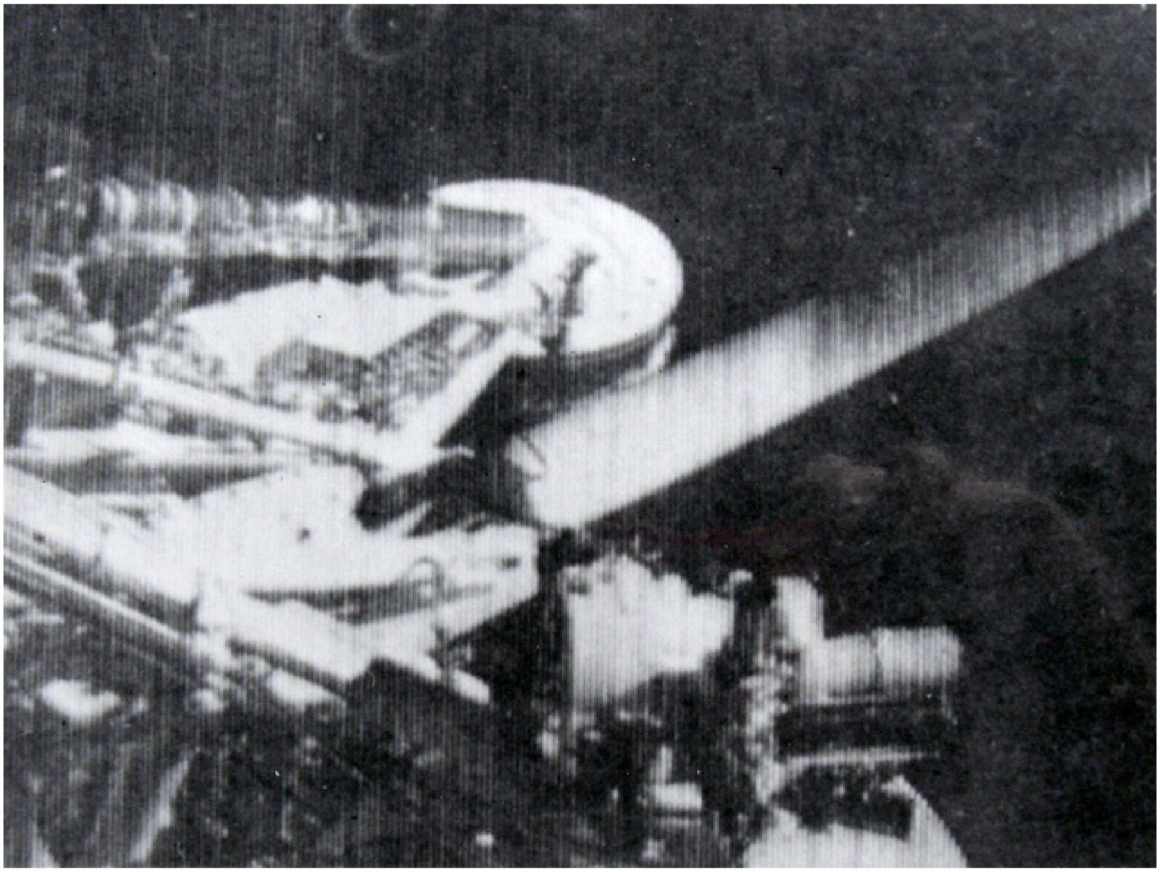

Fig.8. Surveyor I's first low-resolution, 200-line picture clearly showed footpad 3 resting firmly on the lunar surface. The 12-inch diameter footpad is the white, circular object just above the center in this photo. Also seen are landing leg 3, omni antenna B (the white pole extending from the center to the right side of the image) and other parts of the spacecraft.

spacecraft touched down softly at 7.5 mph (12 kph), rebounding slightly as the shock absorbers on its three legs were compressed and re-extended. Strain gages on each shock absorber would help to determine the bearing strength of the surface.

I cheered along with the people in California. So did my father, although he later confessed that he was stunned. As he now recalls, "When Surveyor I made a perfect landing on the Moon, I couldn't believe it. The problems the engineers had to solve and the odds against success were such that I did not expect the first mission to make it. I don't think anyone else in the program thought that it would, either."

But the night was far from over for Mellberg, or the engineers controlling Surveyor I from the SFOF in Pasadena. Everyone was anxious to see the spacecraft's first pictures from the Moon — no one more so than my father. Five long years of hard work had come down to another 36-minute wait.

Before any pictures could be taken, dozens of commands had to be sent to Surveyor I to shut down its landing systems, determine the overall condition of the spacecraft and

Fig. 9. Among Surveyor I's first high-resolution, 600-line pictures was this view looking toward the southeast of a nearby 18-inch (0.5 m) rock and a shallow10 foot (3 m) crater.

power up the survey camera. The first images would be low resolution, 200-line pictures transmitted by the omni-directional antennas. (Home television sets in North America use 525 lines.) High resolution, 600-line pictures would have to wait until the high-gain antenna could be pointed toward Earth. The first picture would show footpad 3.

"The picture of the footpad is the most important thing in my opinion," Harold Urey told George Herman as the world awaited that image. "Has it sunk into the surface? It will be then that the men working on this will be able to deduce from what they see exactly what it means about the strength of the Moon."

In short, that first picture might reveal whether or not an Apollo spacecraft could land on the Moon and Apollo astronauts could explore its surface.

A little more than half an hour after landing, at 0653 GMT (0253 EDT), Surveyor I transmitted a high contrast image of footpad 3 and other parts of the spacecraft, including landing leg 3 and omni antenna B. The camera's iris was set to show those structural components rather than the lunar surface, which appeared dark and indistinct in the background. "It looks very much as though the pad has remained definitely above the surface," Harold Urey remarked. Surveyor I was resting on firm ground.

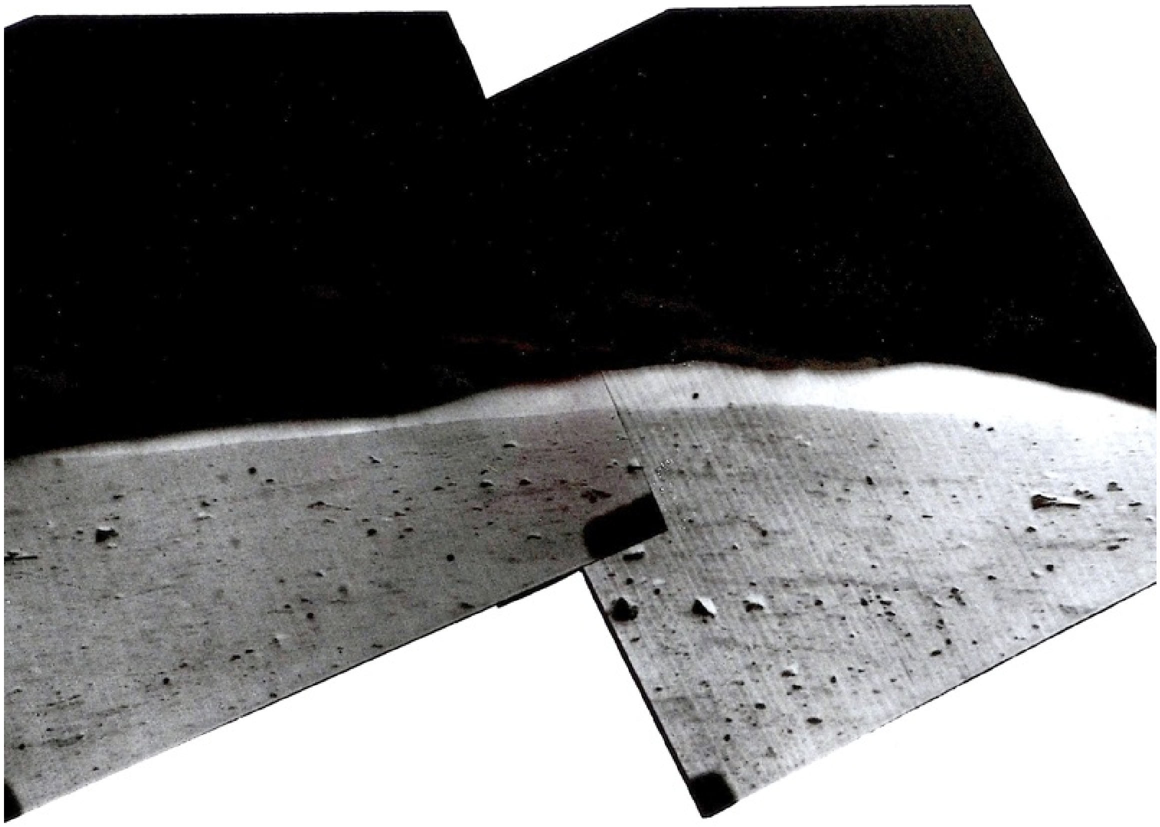

Fig. 10. Surveyor I imaged the tops of a mountain chain approximately 12 miles (19 km) northeast of the landing site. The mountains are part of the 69-mile (112 km) diameter Flamsteed P "ghost" crater. Their position helped determine the location of Surveyor I inside an ancient depression that was flooded by lava flows a billion years ago. A ring of mountains rising above the dark floor of Flamsteed P now marks the raised rim of the buried crater.

"I was disappointed with the pictures at first," Frank Mellberg recalls. "The 200-line images did not show many details of the lunar landscape. But after they switched to the 600-line mode, the pictures were beautiful!"

Only fourteen 200-line photos were taken before JPL controllers aligned Surveyor I's solar panel at the Sun and its high-gain antenna toward Earth. The added power soon enabled the transmission of 600-line pictures that revealed a treasure trove of details about the surrounding terrain. There were rocks of all sizes scattered about the surface, from tiny pebbles to large boulders. Southeast of the spacecraft, a nearby rock about 18 inches long (0.5 m) was sitting in clear view, as was a shallow 10 foot (3 m) diameter crater approximately 36 feet (11 m) away. It was obvious that Surveyor I's images offered significantly greater resolution than Luna-9's.

I missed the initial 600-line images as I finally went to bed, tired, but thrilled. There were plenty of pictures to see on the morning news when I woke up. Dad had even more to pore over when he reached his office that historic June 2, 1966. He also had a pile of

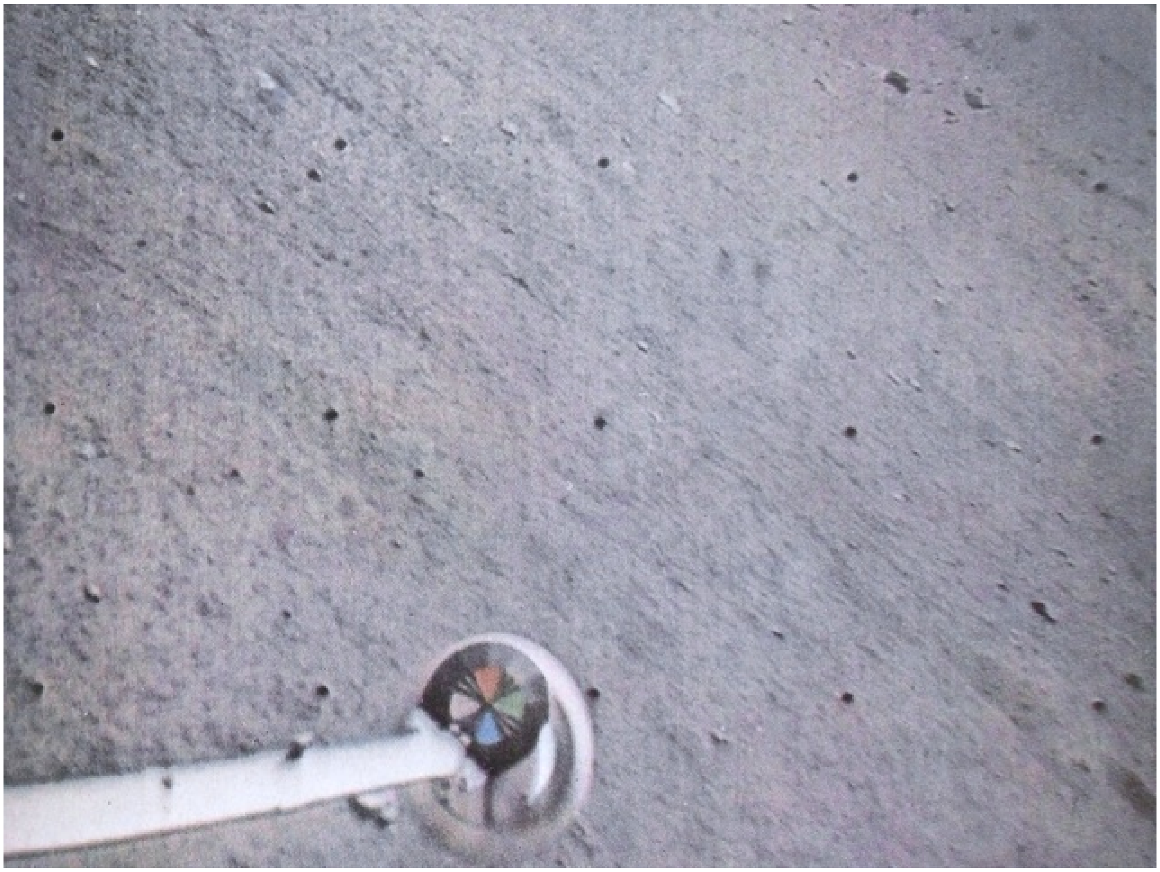

Fig. 11. A photometric target at the tip of omni-directional antenna B provides the only color in this view of the gray lunar landscape as seen by Surveyor I's camera.

messages congratulating him on the success of Surveyor's "eye" on the Moon, as well as many requests for interviews from the news media. One of those requests was from Chicago baseball legend Bill Veeck, who had a 30-minute talk show on WFLD-TV each weeknight. I accompanied my father to WFLD's studios on the 44th floor of the Civic Opera Building for the afternoon taping on June 28th. It was a treat for both of us to meet Bill Veeck. Bill asked insightful questions, and my father gave excellent answers. He brought along a one-fifth scale model of Surveyor that he had built to help explain the spacecraft and its camera to Veeck's audience. Dad's model 'starred' atop a Moon float in the Evanston (Illinois) Fourth of July Parade a few days later. It was a fitting addition given the parade's theme that year: "American Inventions."

Mellberg was also invited to give a lecture about Surveyor and the Moon at the Adler Planetarium in Chicago. That was another interesting experience. But more than anything else, he probably enjoyed sitting in the audience for NASA's Surveyor I Press Conference in Washington on June 16, two days after the spacecraft experienced its first lunar sunset.

A panel of lunar scientists, including Eugene Shoemaker and “J.” Rennilson, provided a preliminary analysis of the information returned by Surveyor I. Dr. Shoemaker was the Principal Investigator for Surveyor’s Television Experiment. His focus was on the geological implications of the Surveyor I images. Rennilson was the Cognizant Scientist for the Surveyor I Television Experiment. He was in charge of the camera’s final, pre-launch calibration tests at Cape Kennedy and described the first color pictures from the Moon.

Frank Mellberg’s notes from the Surveyor I Press Conference record some of the briefing highlights. Shoemaker projected several of the most interesting images taken by the spacecraft and provided his interpretations of each.

“I think what the pictures show us,” Shoemaker told the audience, “is this fragmental surface layer has been produced by repetitive bombardment.” He was describing the soil-like surface layer of the Moon which had been repeatedly pulverized and churned by meteoroid impacts over hundreds of millions of years. The process produced a firm topsoil (the lunar regolith) that was peppered with craters and littered with rocks of all sizes.

“It is certainly not a deep sea of very fine dust . . . it is very gritty and bouldery, pebbly, silt-like material. It is relatively easily disturbed. The effects are not unlike the effects of walking across, say, a plowed field, a freshly plowed field. The consistency is somewhat similar.”

Dr. Leonard Jaffe, JPL Surveyor Project Scientist, added that an Apollo Lunar Module could land on the Moon. “Are there any hazards to a spacecraft?” he asked rhetorically. “Yes . . . there are certainly some big rocks.” A photo of a large boulder field located southwest of Surveyor I illustrated that hazard. But the Lunar Module was being designed so that astronauts could maneuver their craft over and around such dangers.

And what was the Moon’s color? “J.” Rennilson described the filter wheel positioned just above the survey camera’s zoom lens. Taking black & white pictures of the same scene through its red, green and blue filters, technicians were able to construct color images — helped, in part, by color photometric targets mounted on footpad 2 and omni B. The final result: the Moon is “neutral gray.”

LIFE magazine ran a cover story in its July 1, 1966, issue titled “The True Color of the Moon.” It featured a gray rock. National Geographic had a similar article in its October 1966, issue. But the only color seen in the photos was a gold-plated thruster near footpad 2 and the aforementioned photometric targets. More ‘color’ had been smuggled aboard Surveyor I by HAC’s Surveyor Project Chief Scientist. Sheldon Shallon placed a small American flag inside one of the spacecraft’s aluminum tubes before launch. But the Stars and Stripes remained tucked away, and there was no patriotic display adding color to the lunar surface. (Luna-9 had carried two, red metal pennants bearing the State Emblem of the USSR to the Moon.)

Fig. 12. Surveyor I's camera caught its own shadow as the Sun slowly sank in the west near the end of the spacecraft's first lunar day. Panoramic pictures such as this one were assembled inside large hemispheres by pasting dozens of overlapping narrow-angle images together. These mosaics provided highly detailed, distortion-free views of the surrounding terrain.

Surveyor Legacy

Between June 2 and June 14, Surveyor I took more than 10,300 photos of the lunar surface and responded to more than 100,000 ground commands. Near the end of its first lunar day, Surveyor I took several self-portraits as its spindly shape cast a long shadow across the Moon's surface. After the Sun set on June 14, 1966 (a Moon day is 14 Earth days long), Surveyor I took several pictures of the solar corona, as well as images of footpad 2 bathed in earthlight. Few people expected the spacecraft to survive the frigid lunar night. But the plucky lunar lander responded to commands on July 6, beaming back another 618 pictures. Surveyor I continued to answer calls from home until January 7, 1967. It was one of America's most successful space missions.

Six additional Surveyors were sent to the Moon.

Surveyor II was launched on September 20, 1966. But it encountered a failure with one of its vernier engines during the mid-course maneuver, and the spacecraft began to tumble before impacting the Moon.

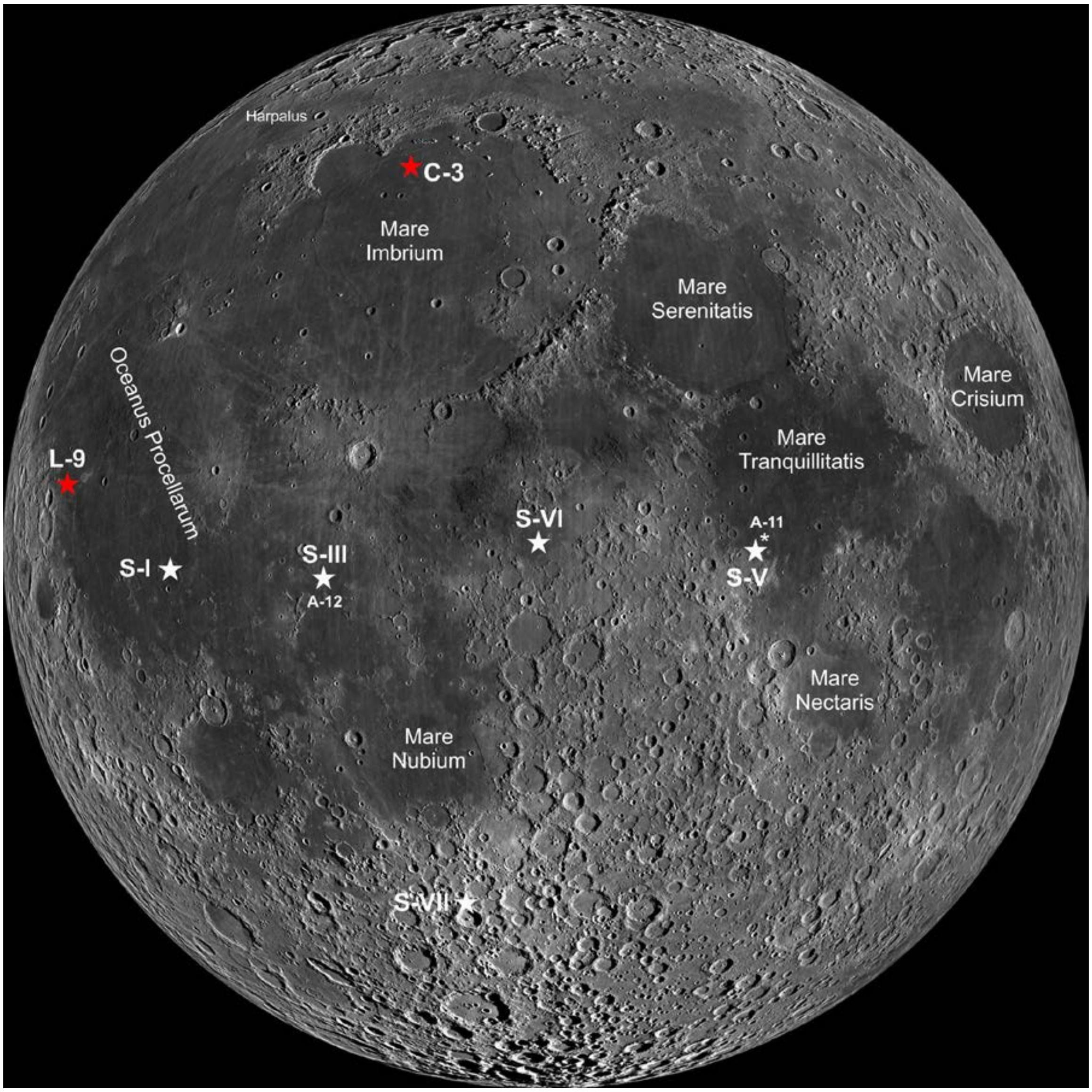

Fig. 13. Five Surveyor (S) spacecraft successfully landed on the Moon. Surveyor V touched down in the *Sea of Tranquility*, not far from where Apollo 11 (A) landed two years later. The Apollo 12 astronauts visited Surveyor III and returned its camera to Earth. The Luna-9 (L) and Chang'e 3 (C) landing sites are also noted. (NASA/LROC/ASU/GSFC Lunar Reconnaissance Orbiter photomosaic base map)

Surveyor III was another outstanding success, touching down inside a 600-foot (180 meter) diameter crater in the *Ocean of Storms* on April 19, 1967. It carried a surface sampler (an extendable scooper) that dug trenches in the lunar soil and picked up lunar rocks. Surveyor III also took the first pictures of Earth as seen from the lunar surface.

Surveyor IV was launched on July 14, 1967. All appeared to be going well until just two and a half minutes before the planned landing when signals from the spacecraft abruptly stopped.

Surveyor V touched down in the *Sea of Tranquility* on September 10, 1967. It carried an alpha particle scattering instrument that successfully analyzed the chemical composition of the lunar soil beneath the spacecraft. It was very similar to terrestrial basalt — igneous rock formed by the rapid cooling of basaltic lava.

Surveyor VI landed in *Sinus Medii* (*Central Bay*) near the center of the Moon's near side on November 9, 1967. It, too, carried an alpha scattering instrument, and the results were the same as Surveyor V's. Surveyor VI became the first spacecraft to lift off from the Moon when it fired its vernier engines on November 17 to make a short hop across the surface. It returned more than 30,000 pictures to Earth.

Surveyor VII touched down near the north rim of the bright crater Tycho on January 9, 1968. All previous Surveyors had landed in the Apollo Zone, smooth "mare" areas near the lunar equator that were deemed most suitable for manned lunar landings. Surveyor VII was sent to a highlands region in the Moon's southern hemisphere on a purely scientific mission. It carried a surface sampler and an alpha particle scattering instrument.

On the whole, the highland soil demonstrated the same physical properties as the mare material, but the chemical analysis showed a lower content in the iron group of elements (titanium, vanadium, chromium, manganese, iron, cobalt, nickel and copper). Eugene Shoemaker would later identify this coarse-grained highland material as "anorthositic gabbro" composed of minerals (mostly plagioclase) formed deep beneath the ancient lunar crust. Paul Spudis notes that Dr. Shoemaker's eventual conclusions were based on samples obtained during the Apollo 11 mission. They were supported by the Surveyor VII spectrometer results.

Five highly successful Surveyor missions had touched the lunar surface via robotic instruments. Now it was time to send humans to the Moon.

As Apollo 17 Scientist-Astronaut Harrison H. Schmitt notes in retrospect, "With President John F. Kennedy's challenge for Americans to go to the Moon in 1961, Surveyor became part of the Apollo Program. Along with Ranger and Lunar Orbiter, Surveyor had been initiated previously by NASA as space science projects. Each of them contributed critically to the design of Apollo spacecraft and equipment, to experience in lunar flight operations, and to the planning of lunar exploration. Project Surveyor, in particular, removed any doubt that it was possible for Americans to land on the Moon and explore its surface."

Dr. Schmitt, the first geologist and last human to set foot on the Moon, adds, "Surveyor also provided the photographic and geotechnical data for Eugene Shoemaker's detailed characterization of the impact-generated debris layer (the regolith) that covers most of the Moon. This knowledge provided the scientific basis for designing sampling tools, as well as for planning much of the practical field training of the Apollo astronauts."

Justin Rennilson likes to point out that beyond its support role for Apollo, Surveyor achieved many "firsts" in space exploration. Among them . . .

- Surveyor's Atlas-Centaur launch vehicle pioneered the use of liquid hydrogen as a rocket fuel. The Saturn V Moon Rocket made use of liquid hydrogen, as did the Space Shuttle. Centaur is still flying today.

- Surveyor I was the first spacecraft to make a completely controlled soft landing on the Moon, paving the way for the Apollo astronauts who made use of similar systems and techniques.

- Surveyor I made the first astronomical observations from the Moon.

- Surveyor I provided the first color images of lunar rocks and soil.

- Surveyor III took the first color images of Earth from the Moon.

- Surveyor III observed the first total solar eclipse from the Moon.

- Surveyor V made the first chemical analysis of lunar soil.

- Surveyor VI made the first takeoff from the Moon.

- Surveyor VII was the first spacecraft to investigate the lunar highlands.

- Surveyor VII took the first image of a constellation (Orion) from the surface of another celestial body (the Moon).

- Surveyor VII's camera was the first instrument to detect laser beams directed from Earth to the Moon.

- Surveyor missions yielded the first indications that lunar soil might be levitated, perhaps by an electrostatic field, during the time after sunset (and probably before sunrise). This "horizon glow" phenomenon is still being investigated through analysis of data from the recent LADEE mission. Thus far, no confirmation of soil levitation has been made.

America's first Moon landings marked the beginning of an exciting, but short-lived era of lunar surface exploration by the United States of America.

Epilogue

Apollo 12, the second manned lunar landing mission, touched down less than 600 feet (180 meters) from Surveyor III on November 19, 1969. Mission Commander Charles "Pete" Conrad made a very precise landing. His Lunar Module "Intrepid" was perched on the rim of Surveyor Crater, and Conrad and Lunar Module Pilot Alan Bean were able to walk to the robot, which had landed on the Moon 31 months earlier. Photographing the

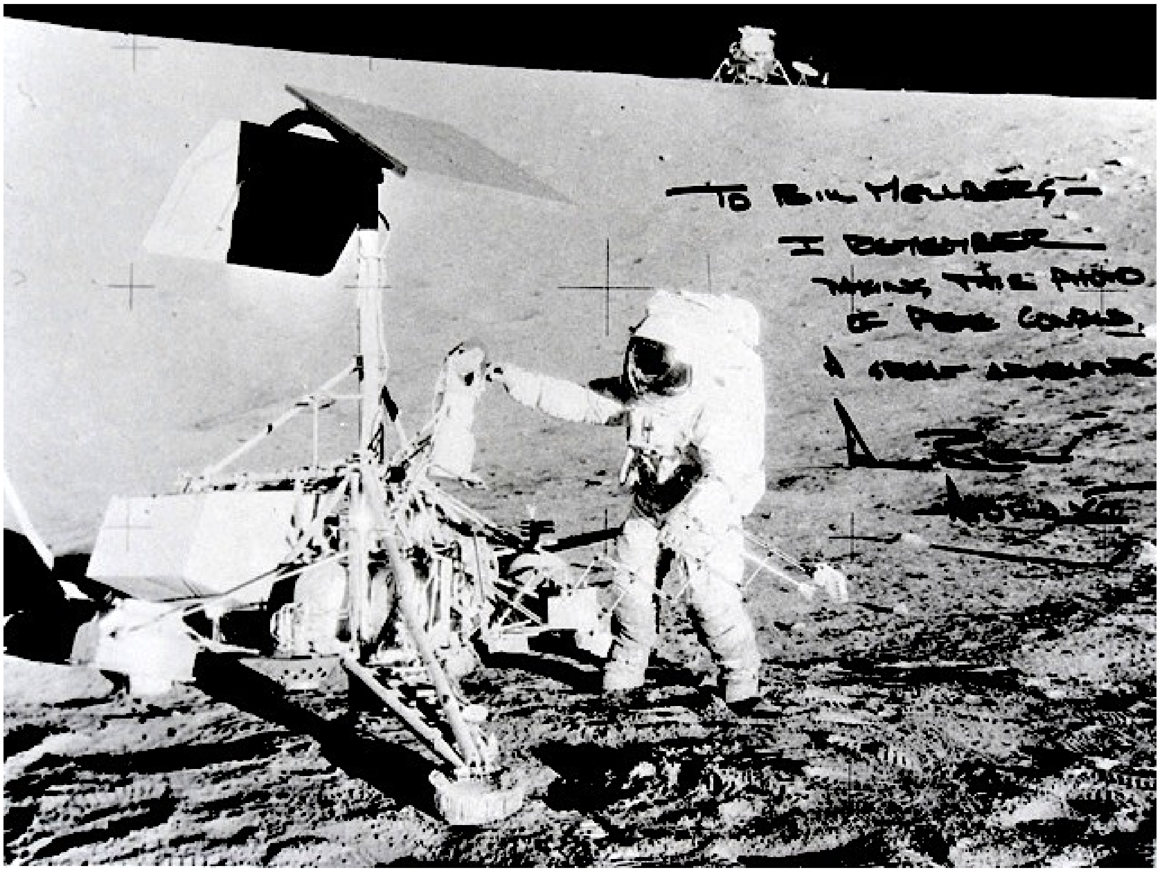

Fig. 14. Apollo 12 Commander “Pete” Conrad points to the Surveyor III camera in a photo taken by Lunar Module Pilot Alan Bean. The Lunar Module “Intrepid” can be seen perched above the lunar robot on the rim of Surveyor Crater. Captain Bean inscribed this copy to the author: “I remember taking this photo of Pete Conrad. A great adventure.”

spacecraft and the area around it to see if any changes had taken place in that time (none had), the astronauts removed Surveyor III’s camera so that the effects of long-term exposure to the lunar environment could be studied.

The Surveyor III camera was brought back to Earth aboard the Apollo 12 Command Module “Yankee Clipper” and first examined at NASA’s Lunar Receiving Laboratory in Houston. The camera eventually made its way back to Bell & Howell for testing on May 15, 1970, five years after the lens assembly had been shipped to Hughes.

A report later issued by Bell & Howell stated, “The lens still functions well, both mechanically and optically.”

Six months after the Surveyor I landing, my father left Bell & Howell to become an engineering consultant, working in association with his former colleague, Dr. Arthur Cox. But Dad and I were invited to B&H to have a look at the Surveyor III camera in the optical lab.

We not only looked at the camera … we held it in our hands! It was a real treat for me to be holding something that had gone from the Earth to the Moon, to be holding a piece of space history. I noticed a streak left on the mirror by Pete Conrad's gloved finger. As Conrad flew past Surveyor III during his final descent, the blast from the Lunar Module's engine covered the robot with a fine coat of lunar dust. Conrad slid his finger down the mirror while inspecting the camera, leaving the streak behind.

My father could hardly believe that the Surveyor III camera he was now holding had spent 31 months on the Moon. Nine years earlier, when he sketched the preliminary lens design in a California hotel room, he could not have imagined this moment. It was the unexpected culmination of a dream.

The Surveyor III camera would make one last trip — to the Smithsonian Air and Space Museum in Washington. It has been on display there ever since.

Dad was involved with many interesting projects during the course of his long engineering career. He helped design instruments for the Pioneer and Galileo probes that explored the atmospheres of Venus and Jupiter. He worked on Night Vision Goggles for Harrier jump jet pilots. And he was involved with a host of other challenging endeavors. But Surveyor was the highlight of his career. It was a once-in-a-lifetime opportunity to be part of a great adventure — the first exploration of another world!

Somewhere in China, there must be other engineers who feel a similar sense of satisfaction and pride in their success with Chang'e 3 and Yutu. They are now busy designing and building the next generation of lunar landers.

December 7, 1972. Six years after Surveyor I landed on the Moon, my father and I enjoyed one more chapter in space history. We were at the Kennedy Space Center to witness the launch of Apollo 17, the last manned voyage to the Moon. We saw Eugene Cernan, Ronald Evans and Harrison Schmitt as they headed toward Pad 39A. We talked with Astronaut Thomas Stafford, who had already flown to the Moon as Commander of Apollo 10. And we saw and heard and felt the mighty Saturn V Moon Rocket as it left Earth that night. After a remarkably successful mission to the Valley of Taurus-Littrow, the Apollo 17 crew returned to Earth on December 19. (**Fig. 15**)

Ten years earlier, hundreds of thousands of Americans, including Frank Mellberg, were working day and night to make a dream come true — to put a man on the Moon. Now it was all over. But what a decade it had been!

Fig. 15. Bill (*left*) and Frank Mellberg (*center*) with the last American to set foot on the Moon, Harrison H. (Jack) Schmitt (*right*), together again in Chicago in 2009, 37 years after the launch of Apollo 17.

Front Cover Caption:

A Surveyor spacecraft is illustrated, as it would appear after landing on the Moon's surface in this painting by Hughes Aircraft Company artist, Carlos Lopez (ca. 1964).

Back Cover Caption:

A Bell & Howell advertisement from June 1966 comparing Surveyor I's "eye" to the zoom lens in the firm's home movie cameras. Frank Mellberg built the Surveyor model (see **Fig. 1**).


A Bell & Howell zoom lens is on the moon...
Surveyor: designed and developed by Hughes Aircraft Company for the National Aeronautics and Space Administration under the direction of the Jet Propulsion Laboratory. (A scale model of Surveyor is shown.)
It's the "eye" of the television camera on Surveyor I.
It had to be able to sustain 30 times the pull of gravity at blast-off. Its glass elements had to be protected from vibration damage and potential radiation discoloring. It had to withstand the extremes of heat and cold on the moon—ranging from 250° fahrenheit to 250° below zero.
Once in the lunar vacuum, it had to zoom and focus perfectly by electronic commands from a control panel 230,930 miles away.
The lunar lens has performed to specifications.
We like to think we were chosen to design and build it because of our continuing commitment to build photographic instruments a little better than they really have to be.
and in this camera.
For instance, this Bell & Howell Focus-Tronic Super 8 home movie camera employs a zoom lens which is quite similar in optical design to the lunar lens. Both grew out of the same technological skill.
Bell & Howell®