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Ranger to the Moon

The full story of the successful mission of Ranger VII to take the first close-up pictures of the surface of the moon.

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Ranger VII was launched at 11:50:07.873 EST on July 28, 1964. Although it was not known at the time, this launch was destined to become a landmark in space exploration history. It was to break a string of disappointments in lunar exploration that dates back to August 17, 1958, when the first of a series of U.S. lunar space launches, conducted by different organizations under the sponsorship of different government agencies, was attempted.

After a number of these earlier attempts on smaller launch vehicles, it was decided by the National Aeronautics and Space Administration to embark upon a project based on the Atlas-Agena B launch vehicle. To be known as the Ranger Project, this would initiate a big, but inevitable, step in spacecraft design that was made possible by the higher performance Atlas-Agena B. This step—that of attitude stabilization and control—was fundamental to the development of spacecraft that would be capable of efficiently and effectively exploring the moon and the planets. It was important to initiate this step as soon as it was practical; and, although the spacecraft weight permitted by the launch vehicle performance was none too ample, it was decided that the step could and should be taken.

The first two Rangers were not lunar shots. They were to go into elliptical earth orbits to evaluate and test out the new spacecraft design and to perform some scientific measurements on the space environment. The third Ranger was the first to be scheduled as a lunar shot.

These first three Rangers were destined to pay the penalty of pioneering a new launch vehicle; inflight difficulties kept them from achieving their respective mission objectives. As originally planned, a number of military space launches, prior to the first Ranger launch, were scheduled to use this launch vehicle—which was (and still is) a national space booster provided by the military. Because of changes in the schedule and content of the military space program, however, these Ranger launches were among the first for this launch vehicle, which, after this early period, has had a good record.

The next two Rangers were properly injected by the launch vehicle but there were failures in the spacecraft itself. At this point, a thorough review was conducted of the design, fabrication, and quality practices utilized throughout the entire project. Particular emphasis was given to the higher reliability components that had become available since the original design; and to the newly developing experience relating to the performance of components and materials in the space environment.

This review led to a number of changes in detail designs and in fabrication and quality procedures. It also resulted in the deletion of the heat sterilization practice that had been applied to these early Rangers. This latter step was made possible by a series of studies which had determined that even if earth life could survive in the lunar environment, it most probably would remain contained in a very small local area. In addition, there was evidence that heat sterilization actually did reduce the reliability of equipment to a degree greater than was originally expected.

A change in mission, as had been planned for some time, also was implemented at this point in the program. Rangers III through V had intended to land a small package, designed to withstand a rather rough landing (100 to 200 ft/sec impact velocity) on the lunar surface. Beginning with the sixth Ranger, the objective was to obtain high resolution close-up photographs of samples of the lunar surface, particularly areas similar to those of interest to the Manned Lunar Landing Program. As a result, Ranger VI carried, for the very first time, a payload package designed to permit the taking and transmitting to earth of a series of good quality high resolution photographs.

Ranger VI did not obtain lunar photographs, due to a malfunction within this new TV payload package. The rest of the spacecraft worked perfectly, establishing a record in lunar flight precision and providing new data on such items as the mass of the moon and the mass of the earth, which are important both scientifically and for space navigation.

The malfunction in the TV package was determined to have been caused by an unintended (and, to this date, not completely explainable) turn-on of the package during the boost phase, at a time when the spacecraft was subjected to critical electrical arcing pressures. The resultant arcing caused certain circuits in the TV package, including the high voltage circuits in its transmitters, to burn out. As a result, design changes were made on Ranger VII to ensure that the TV package could not be turned on during this critical boost phase.

This was the background at the time of launch of Ranger VII. All of the elements necessary to carry the payload package to the vicinity of the moon, and to point it in the proper direction—including all of those elements necessary to and inherent in the attitude-controlled design concept—had worked perfectly on the previous shot. These same concepts, pioneered by the Rangers, had previously been adapted to — and had made possible — the successful Mariner II Venus probe, which had demonstrated the basic soundness of the approach. (As a result of the experience and developments of both the Ranger and Mariner II, these same concepts have now been further adapted to the forthcoming Mars spacecraft.)

Action had further been taken to preclude the malfunction that had plagued the previous launch. All elements of the project had successfully passed through ground tests. Thus, to the best of our ability to predict, there was no specific reason to expect anything but success. On the other hand, in projects of this nature, one can never be completely sure that all of the weaknesses of the design have been eliminated, or that a "random" failure will not occur, since it is not possible to build equipment of this type that will have a zero failure rate.

The Moon and Trajectory Considerations

In 1609 Galileo described his observations of the moon as follows:

"The prominences there are mainly very similar to our most rugged and steepest mountains, and some of them are seen to to be drawn out in long tracts of hundreds of miles. Others are in more compact groups, and there are also many detached and solitary rocks, precipitous and craggy. But what occur most frequently there are certain ridges, somewhat raised, which surround and enclose plains of different sizes and various shapes but for the most part, circular. In the middle of many of these there is a mountain in sharp relief and some few are filled with a dark substance similar to that of the large spots that are seen with the naked eye; these are the largest ones, and there are a very great number of smaller ones, almost all of them circular."

Galileo first gazed at the moon through a telescope more than 350 years ago. Up to Ranger VII, however, we had seen little more of the detail of the moon's surface than did Galileo. Our modern telescopes are better, but they still stand the same distance from the moon, and on the same platform —the earth. We still peer through the same mantle of atmosphere that hindered Galileo's viewing.

Although the lunar surface conditions still eluded us, we had learned a few facts about the moon. We conclude that the moon has no surface water and no appreciable atmosphere. For all practical purposes, its distance from the sun is the same as the earth's, and so it receives the same amount of heat from the sun. But, due to the lack of atmosphere, the temperature on the moon's surface ranges from 261°F at noon (hotter than boiling water on earth), to −243°F at midnight (more than twice as cold as any place on earth).

Such extremes of temperature, coupled with the lack of atmosphere on the moon, would presumably preclude the existence of any form of life as we know it. Still, the possibility of the existence of so-called sub-life forms must be considered. We cannot predict the action of atoms and molecules at, or just under, the surface of the moon, where they have been under eon-long bombardment by undiluted solar radiation and by cosmic rays. The formation of complex macromolecules may be possible.

Recent studies have made it appear probable that the great craters on the moon are impact craters rather than volcanic craters. Although the great craters appear to be meteoric in origin, this does not imply that no volcanic activity can exist on the moon. On the contrary, there are, for example, rows of craterlets near Copernicus which may be due to volcanic activity. One of the most interesting observations in the past few years was made in a portion of the crater Alphonsus. A temporary haziness was found which lasted long enough for a spectrogram to be obtained, confirming the existence of carbonaceous molecules and some yet unidentified species. So gases do exist, at least for a short time, on the surface of the moon.

One school of thought suggests that the maria, or plains, as well as the centers of many of the old craters, are filled with dust. The thickness of the layer of dust is estimated by the total amount of rock which could have been worn from all of the old crater walls in the highlands. On this basis, a number of 1 kilometer is reached for the maximum dust depth—that is, a little over ½ mile.

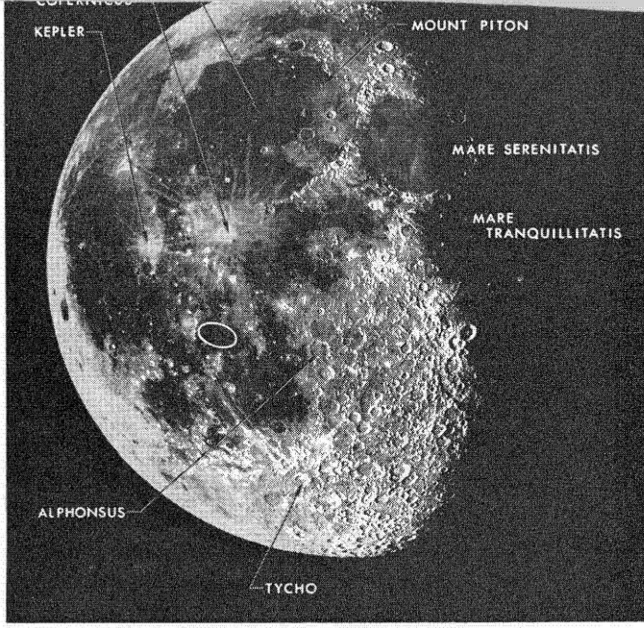
Experiments have indicated that dust, in a vacuum such as on the surface of the moon, would tend to become hard packed. So we can imagine that any deep dust layer on the moon would resemble pumice more than the dust with which we are familiar. Accordingly, there would seem to be little danger of our spacecraft being buried in a half-mile of loose dust. However, there are also the theories of suspended dust, sintered dust, and no dust at all. Thus, the most important task we must accomplish in the first lunar explorations is to determine the exact nature of the moon's surface.

In light of our vast ignorance regarding the nature of the lunar surface—the topography as well as the physical and chemical properties—it was quite natural to look for ways to obtain close-up television photographs of samples of the surface. However, the moon is not an easy object to photograph. Its color and texture and contrast variation are minimum, and it reflects relatively little light.

Thus, the best photographs can be obtained during lunar sunrise or sunset conditions—that is, close to the terminator (the line dividing the sunlight and dark halves of the moon)—where shadow effects are most prominent, and yet where there is still sufficient light to give good photographs.

Estimates of the available light, prior to Ranger VII data, indicated that, in order to be sure of sufficient light for the TV system to obtain good pictures, one should not attempt to go closer than about 20° from the terminator in the sunlight half of the moon. There was, however, considerable uncertainty as to the actual close-up lighting conditions to expect. From the contrast and shadow effects, it would have been better to be able to go even closer to the terminator.

The maria areas—the relatively flat areas which



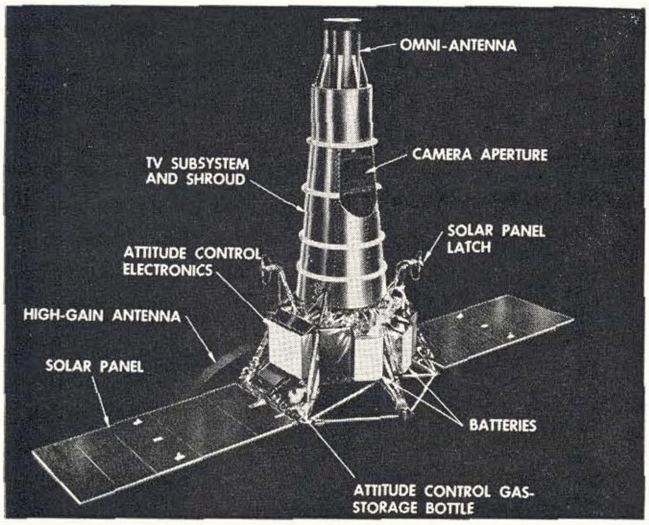
Some prominent physical features on the east side of the moon. The circled area, which shows where Ranger VII landed, is now officially known as "Mare Cognitum" —the sea that is well known.

resemble a sea, as their name implies—were the areas selected to be photographed first. This type of lunar terrain has been selected as tentative landing areas for the Manned Lunar Landing, and is also of considerable scientific interest.

The lighting constraint conditions, coupled with such factors as the characteristics of earth-lunar trajectories, and specific design characteristics of the spacecraft, limit the times when launches can be attempted to a one- or two-hour period on each day of a five- or six-day period, once each lunar cycle (approximately once a month). Furthermore, the lighting constraint requirement of taking pictures at a given distance from the terminator requires that the selected target areas change for each of the five or six possible launch days. The practice has been to select, prior to launch, a few possible target areas for each permissible launch day, and then, after launch—when the conditions of the spacecraft and its actual injected trajectory are known—to select one as the actual target area, and to perform the midcourse maneuver accordingly.

The Spacecraft

The Ranger VII spacecraft consists of the power, telecommunications, guidance and control, propulsion, temperature control and pyrotechnics subsystems, plus structure, and the television camera payload. The design provides a fully attitude-stabilized system using solar panel power and providing high-gain directional communication with the earth. In the stowed position, the solar panels fold up along the side of the camera tower and the high-



gain antenna folds under the spacecraft structure. The basic structure is hexagonal in shape with the solar panels hinging from opposite sides of the hexagon. The antenna is hinged from a corner of the hexagon between the solar panels. The camera aperture is on the opposite side away from the high-gain antenna. In the flight configuration the spacecraft has a height of about ten feet, span of about fifteen feet, and weighs just over 800 lbs.

Power is supplied by both batteries and solar panels. The batteries are used whenever the solar panels are not oriented at the sun. The selection is performed automatically by power switching and logic circuitry in the power subsystem.

The telecommunication subsystem consists of the antenna, radio, command, and telemetry subsystems. Two antennas are used. On top of the camera subsystem tower is an omnidirectional antenna which receives the signals transmitted from the earth and which transmits spacecraft data to the earth whenever the high-gain antenna is not oriented at the earth. The high-gain antenna is used to transmit both the spacecraft engineering telemetry and the camera subsystem video signals.

The radio subsystem contains the receiver for two-way doppler and ground commands and the transmitter for sending spacecraft signals back to earth. Phase modulation techniques are used in both the ground commands and the spacecraft telemetry modulation of the transmitter signal.

The command subsystem decodes the subcarrier recovered by the receiver. It provides decoded real-time commands directly to the appropriate subsystem and stored command data to the central computer and sequencer (CC&S) in the guidance and control subsystem.

The telemetry subsystem provides ten channels of 110 separate measurements. Complete spacecraft engineering telemetry is made available to assess the status and performance of the various spacecraft subsystems. The telemetry subsystem is also used to verify the receipt and action upon both real-time and stored commands.

The guidance and control subsystem consists of the CC&S and the guidance and attitude control units. The sequencer stores commands inserted prior to launch, and by radio command, and has a timing system for controlling spacecraft operation in accordance with these commands. The computer provides a velocity increment sensing system to provide midcourse motor shut-off at the prescribed time. Several command sequences are initiated by radio command and then controlled by the CC&S.

The guidance and attitude control subsystem provides the equipment to permit sun and earth acquisition and to attain and maintain specific command attitudes for midcourse and terminal maneuvers. Optical sensors are used to lock onto the sun and earth. Small cold gas jets are used to turn the spacecraft in space. Pitch and yaw turns are used to obtain and maintain sun orientation.

The sun-spacecraft line is defined as the roll axis of the spacecraft. The earth sensor is located on the high-gain antenna hinges. Earth lock is maintained by automatically controlling the roll jets and the antenna hinge-angle servo.

The guidance and attitude control system also contains an inertial attitude reference system. The system is used to attain and maintain a commanded attitude relative to the sun-spacecraft-earth coordinate system for the midcourse or terminal maneuver.

The propulsion system used in the midcourse maneuver is a mono-propellant system using hydrazine. A small quantity of oxidizer is used to initiate the combustion, which is maintained by aluminum oxide pellets acting as a catalyst. The engine can impart a velocity change of from 10 cm/sec. to approximately 60 meter/sec. to the spacecraft.

Spacecraft temperature control is achieved by passive techniques involving the proper selection of surface finishes and controlling the internal heat transfer. Local temperatures are, therefore, dependent upon solar energy absorption, energy absorption from the earth, radiation of energy into space, heat from internal power dissipation, and heat transfer to or from other spacecraft components. Extensive telemetry of temperatures throughout the spacecraft permits a check of temperature-control success for adjustment on subsequent flights.

The television subsystem is mounted on top of the basic hexagonal bus and consists of six cameras, associated control and video circuitry, power system, thermal control system, and transmitters to send the video back to the earth.

Mission reliability is enhanced by providing as much isolation as possible between the wide-angle full-scan cameras and the narrower-angle partial-scan cameras.

The Ranger VII Flight

The first attempt to launch Ranger VII was made on July 27, 1964. This was the first day of the six-day launch period. This first attempt was unsuccessful because difficulties with some of the ground guidance equipment could not be resolved in time to permit the launch during the available launch window.

A successful launch was accomplished at the beginning of the launch window on the following day, July 28, after a very smooth countdown. The launch vehicle, an Atlas D-Agena B, rose vertically then rolled to an azimuth of 97° and followed a programmed pitch maneuver until booster cutoff. During the Atlas sustainer and vernier phases, adjustment in vehicle attitude and engine cutoff times were commanded, as required, by the ground guidance computer, to adjust the attitude and velocity at Atlas vernier engine cutoff.

After the Agena separated from the Atlas and pitched down to a horizontal attitude, the Agena stage ignited and burned until a pre-set velocity increase had been achieved. At this time the Agena-spacecraft combination was coasting in a nearly circular parking orbit in a southeasterly direction at an altitude of 116 miles and traveling 17,400 miles per hour. After coasting in the parking orbit for 20 minutes, determined by the ground guidance computer and transmitted to the Agena during the Atlas vernier phase, a second ignition of the Agena engine occurred. About a minute and a half later, just over the western coast of South Africa, the Agena was cut off, with the Agena-spacecraft combination in a nominal earth-moon transfer orbit and traveling 24,600 miles per hour.

After the injection of the Agena-spacecraft into the lunar trajectory, the spacecraft separated from the Agena and the Agena was given a small retro impulse that was designed to eliminate interference with the spacecraft operation and reduce the chance of the Agena impacting the moon. (Tracking data indicated that the Agena passed the trailing edge of the moon at an altitude of 2,600 miles about three hours after the spacecraft impacted the moon.)

Approximately 60 minutes after launch, the CC&S initiated the sun acquisition sequence, commencing with an order to deploy the solar panels. Explosive pin pullers, holding the solar panels in their launch position, detonated, allowing the spring-loaded solar panels to open and assume their cruise position. After the solar panels were deployed, the CC&S activated the attitude control system. The stabilization and orientation of the spacecraft required for sun acquisition was accomplished in two stages.

During the first stage, gross movements of the spacecraft were reduced by the attitude control system's use of pitch and yaw signals generated by the autopilot's rate gyros. After the spacecraft's movements were dampened and its longitudinal axis was pointing in the general direction of the sun by means of signals from the secondary sun sensors, the second stage began. In this stage, the final pointing of the spacecraft was acomplished by the attitude control system's combining of signals received from its primary sun sensors and from the autopilot's rate gyros.

At the same time that the CC& S ordered sun acquisition, it also ordered the high-gain directional antenna extended. A drive motor extended the antenna to a pre-set hinge angle that was determined before launch.

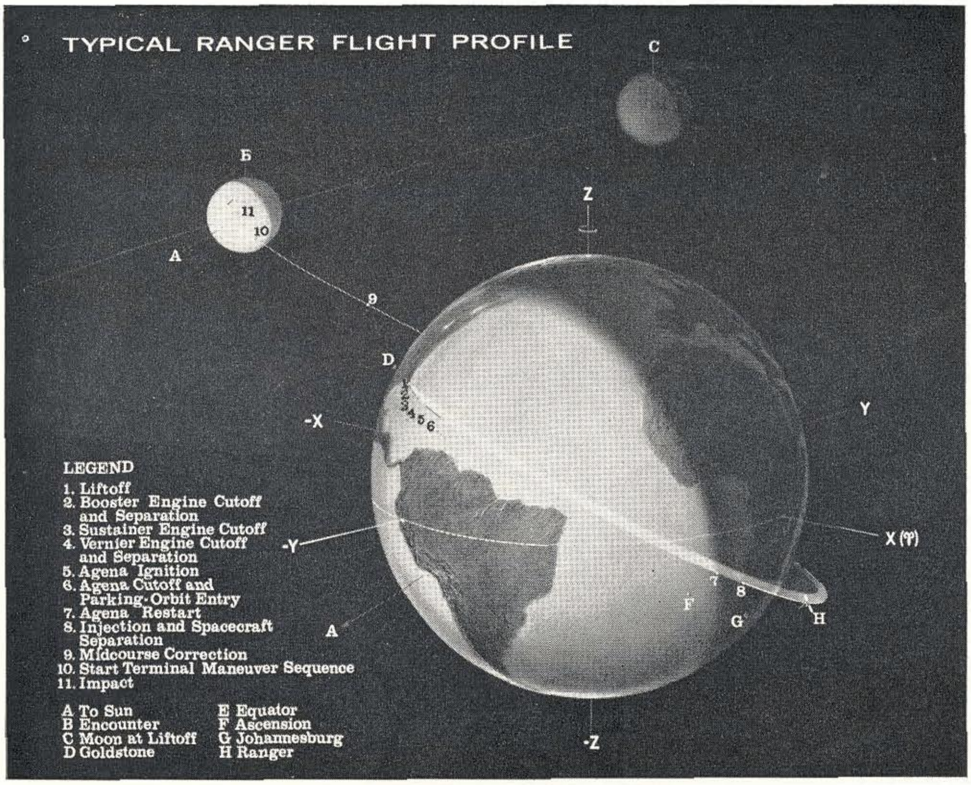
As soon as the spacecraft was locked on the sun, the power system began drawing electric power from the panels.

The next sequence of events commanded by the CC&S was the acquisition of earth by the earth sensor mounted on the high-gain directional antenna. This section was initiated at approximately three and one-half hours after launch. Earth acquisition required 23 minutes out of a maximum total of 30 minutes. To those who were watching the real time telemetered signals for the spacecraft, this seemed like an endless 23 minutes, while waiting to see the indication that the spacecraft in the roll search mode had finally seen and locked on the earth.

With the completion of earth acquisition, the spacecraft was stabilized on three axes – the pitch and yaw, which keep the spacecraft solar panels pointed at the sun; and the roll axis, which keeps the directional antenna pointed toward the earth.

On completion of the earth acquisition sequence, a command was sent from the Woomera, Australia, tracking station to switch the transmitter from the omni-antenna to the high-gain antenna. An increase in signal strength confirmed that the spacecraft had switched to the high-gain antenna and that the earth sensor was locked on the earth. The spacecraft was then in its cruise configuration.

Thirty-one minutes after launch, the Johannesburg, South Africa, station of the Deep Space Instrumentation Facility (DSIF) acquired the space-



craft and from that time until lunar impact continuous communications were maintained by one of the three DSIF stations at Johannesburg, South Africa; Woomera, Australia; and Goldstone, California. Each station has an 85-foot diameter antenna and is equipped to obtain two-way doppler and angle tracking data, to receive telemetry data, and to send commands to the spacecraft as required. The tracking and telemetry data were sent by teletype and telephone lines to the Space Flight Operations Facility (SFOF) at JPL, where they were reduced and analyzed by a group of highly trained specialists, using a large-scale computer system to determine the trajectory of the spacecraft and its performance.

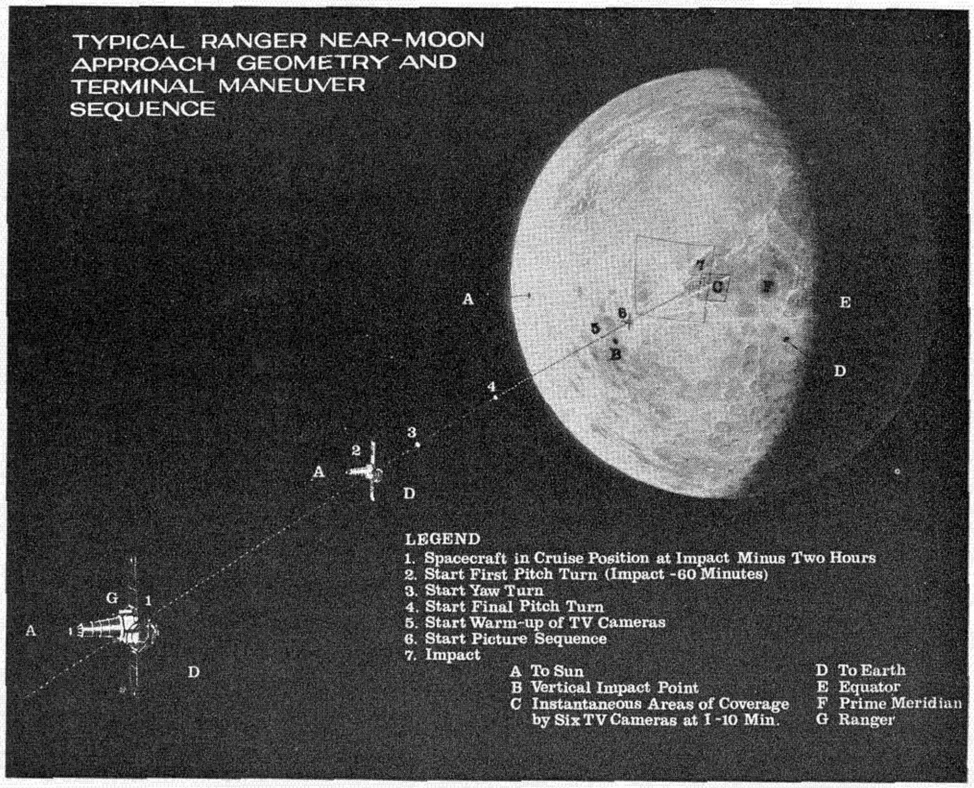
The first few hours of tracking data showed that the spacecraft had been placed on a trajectory that was within its correction capability. The uncorrected trajectory would cause the spacecraft to pass close to the western edge of the moon, then to impact on the back side.

A review of the pre-selected target areas and the spacecraft performance resulted in the primary target for that day being selected. This was the largest rubble-free maria that was the proper distance from the terminator and reasonably close to the equator. The coordinates of the aiming point were 11° south and 21° west. The midcourse maneuver was designed to correct the trajectory to this aiming point. The flight time was also to be adjusted by the midcourse maneuver so that a clock (which had been started at the time of spacecraft separation from the Agena) would turn the full-scan cameras on 17 minutes before the spacecraft would impact the lunar surface. This was done to provide a backup in case the radio command system should fail. The impact time selected was 12:25:30 GMT, July 31, 1964.

The midcourse maneuver was performed about 17 hours after launch when the spacecraft was almost halfway to the moon. This slowed the spacecraft by about 65 miles per hour in its flight to the moon — which essentially permitted the moon to move farther along its orbital path, so that the spacecraft would impact at the desired location at a time that was delayed sufficiently to be compatible with the camera turn-on clock.

The midcourse maneuver commands — roll turn, pitch turn, and velocity increment — were calculated on the computer in the SFOF at JPL and transmitted to the spacecraft from the Goldstone Tracking Station. After verification, by telemetry, that the spacecraft had received the proper commands, an "execute" command was sent to initiate the maneuver at the required time. Since about 97 percent of the velocity increment was in the radial direction toward the earth, the plot of the doppler frequency from the radio tracking gave a good indication that the maneuver had been performed precisely as commanded. The spacecraft proceeded on commands from the CC&S to reacquire the sun, and, a short time later, the earth.

Approximately ten hours after the maneuver,



when sufficient tracking data were available, an orbit was calculated which indicated that the spacecraft would impact very close to the selected aiming point and the specified time. Subsequent computations refined these numbers as more tracking data became available and indicated that the actual impact point was within about six miles of the target point. The actual time of impact was less than 20 seconds different from the selected time.

Studies of the lunar approach geometry indicated that a near-optimum camera alignment existed, with the spacecraft in the sun-oriented attitude, and it was decided not to perform a terminal maneuver. The terminal maneuver was designed to allow the spacecraft to be changed from sun-oriented cruise to any other orientation in case a different attitude would be more optimum for the photography. (The optimum generally aligns the camera axis more nearly with the flight path to minimize the image motion.) On the particular Ranger VII trajectory, one of the cameras (the A camera) already contained the velocity vector within its field of view so that not only was it unnecessary to perform a terminal maneuver, but the impact point would be contained in the entire A-camera sequence.

The cameras turned on exactly as planned and functioned flawlessly, as indeed did the entire spacecraft for the entire flight, until the spacecraft was destroyed on impact with the moon. The video data were recorded on 35mm film and magnetic tape at the Goldstone DSIF station.

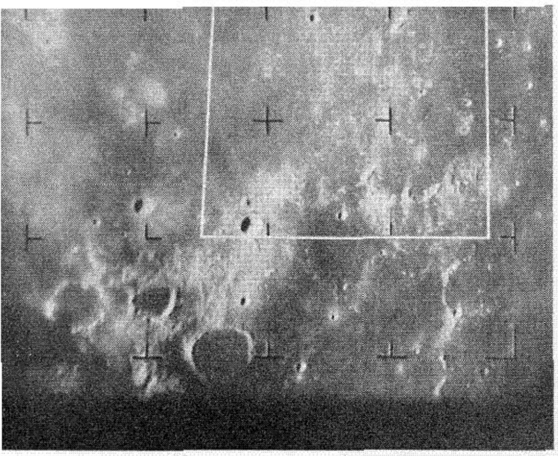
Results and Future Plans

The Ranger VII mission resulted in over 4,300 high quality lunar photos and confirmed the very high degree of lunar flight precision that was initially demonstrated by Ranger VI. Even detailed reviews of the flight records have failed to indicate any evidence of even insignificant malfunctions aboard the spacecraft.

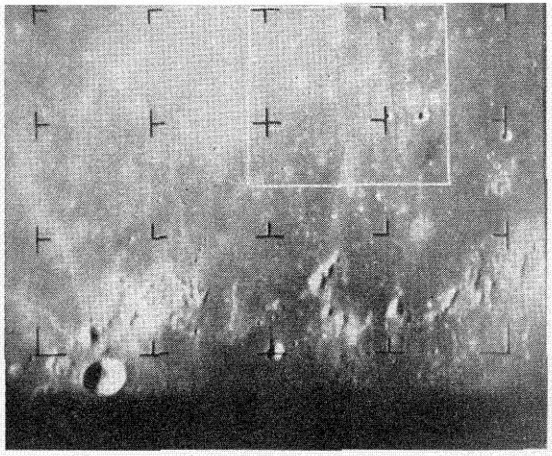
The impact had occurred in a mare region which was well defined but had no name of its own. The International Astronomical Union, at the annual meeting in Hamburg, Germany, adopted the name "Mare Cognitum," in honor of the Ranger VII flight.

At this time an intensive effort is under way to analyze and interpret the large quantity of photographs. This effort is being carried out by the Experimenter team headed by Dr. G. P. Kuiper of the University of Arizona, and his co-investigators: Mr. E. Whitaker of the University of Arizona; Dr. H. Urey of the University of California at San Diego; Dr. E. Shoemaker of the U.S. Geological Survey, Flagstaff, Arizona; and Mr. R. Heacock of JPL.

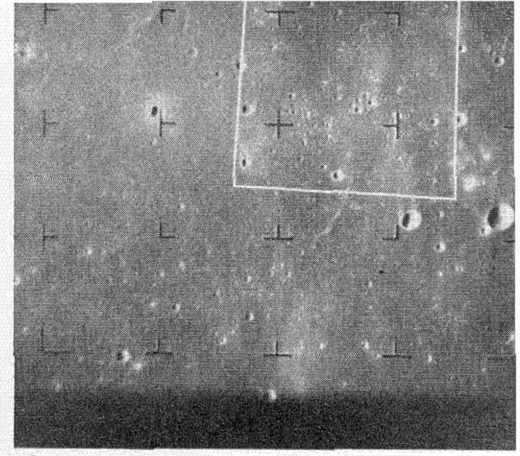
Some very interesting observations have already been made on the basis of the preliminary evaluations of the pictures by the Experimenter team. There appears to be, at least in the areas photographed, almost a complete absence of rocks, boulders, or sharp crevices or fissures of sizes equal to or greater than the resolution of the photos. The reasons for this are not completely clear, but it may



Photograph taken from an altitude of 477 miles is comparable to the resolution obtainable in photographs from the earth.



Photograph taken from altitude of 236 miles, some 2 min. 46 sec. before impact. Each picture covers area marked in preceding picture.



Photograph from an altitude of 84.9 miles covers an area 41.04 miles on a side and shows craters as small as 500 ft. in diameter.

well be due to the long erosion process to which the lunar surface has been subjected. It would not be wind and water erosion as we have on earth, but a "sand-blasting" effect due to high-speed particles from space.

A number of major impact craters like Copernicus, Kepler, and Tycho have very prominent radial features that show up as white rays under full moon illumination. The nature of these rays at resolutions greater than that available from earth-based telescopes has been a subject of considerable speculation. The telescopic observations had shown that these rays contained numerous shallow secondary craters. It was felt by many that these rays also consisted of a white powdery material scattered among a few secondary craters.

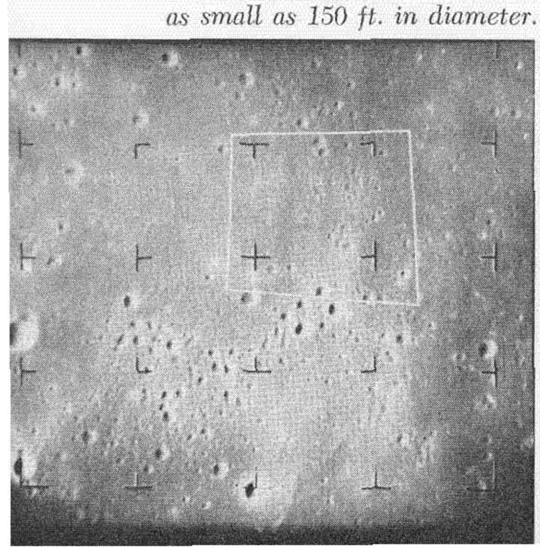
The Ranger VII photos were taken in an area containing faint rays from both of the craters – Copernicus and Tycho. The photos resolved these areas and showed them to consist of numerous small secondary and tertiary craters and apparently not a layer of fine white powder. This is very well shown in the set of nesting A-camera photos shown here. There appears to be a very close correlation between the brightness of a crater ray and the surface density of secondary and tertiary craters.

The highest resolutions obtained are one thousand times better than those from the best earth-based photographs.

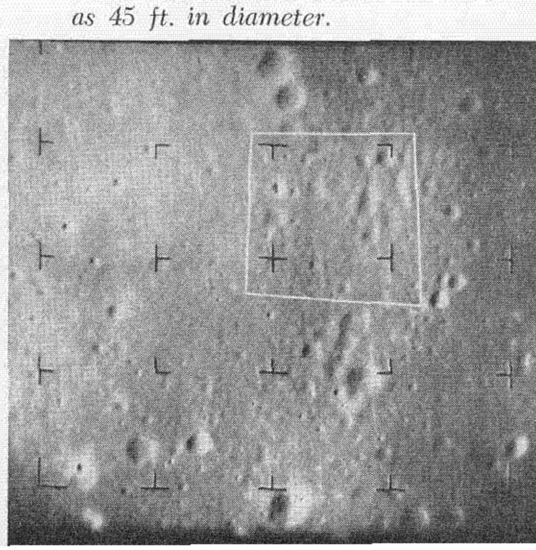
It appears that regions covered by crater rays should be avoided when selecting sites for the landing of instruments or men. A question still to be answered is whether maria that appear smooth and ray-free in telescopic observations are in fact consistently smooth when viewed in detail at resolutions comparable to the Ranger VII photos.

Two more Rangers remain, and these will be launched next year. These spacecraft will be essentially identical to Ranger VII, but the target areas on the moon will be different. If these forthcoming Rangers are as successful as Ranger VII, a great more will be learned about the detailed topography of the moon, and we will be a few steps closer to understanding some of the mysteries, and accomplishing the manned exploration of our closest celestial neighbor.

Photograph taken from an altitude of 33.6 miles shows an area 16.1 miles on a side with craters as small as 150 ft. in diameter.



Photograph taken from an altitude of 11.2 miles shows an area 5.47 miles on a side with craters as small as 45 ft. in diameter.



Photograph taken from an altitude of 3.7 miles, about 2.5 seconds before impact, shows an area about 1.84 miles on a side.