RANGER 1964

JET PROPULSION LABORATORY • CALIFORNIA INSTITUTE OF TECHNOLOGY • PASADENA, CALIFORNIA

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The time has at last arrived when man stands ready to begin the long-awaited lunar explorations.

Introduction

During the year 1964, a series of *Ranger* spacecraft will be sent to photograph the Moon. This series is identified as the *Ranger* Block III Project.

The mission of the Block III *Ranger* flights is to obtain television pictures of the lunar surface which will be of benefit to both the U. S. manned lunar program and the scientific program. These pictures should be at least an order of magnitude better in resolution than any Earth-based photography.

The *Ranger* missions utilize the General Dynamics/Astronautics *Atlas D,* a modified Air Force missile, and the Lockheed *Agena B* second-stage rocket. The *Ranger* spacecraft, mounted atop the *Atlas–Agena* combination launch vehicle, carries a multiple TV camera subsystem built by Radio Corporation of America (RCA). A series of about 3000 video pictures, commencing approximately 10 minutes before lunar impact, is expected to be obtained by each mission. However, because the cameras are set to a wide range of lighting conditions, it is not expected that all 3000 pictures will record useful information.

Success of the *Ranger* Project is dependent upon the proper functioning of four major systems:

(1) The Spacecraft System.

(2) The Launch Vehicle System.

(3) The Space Flight Operations System.

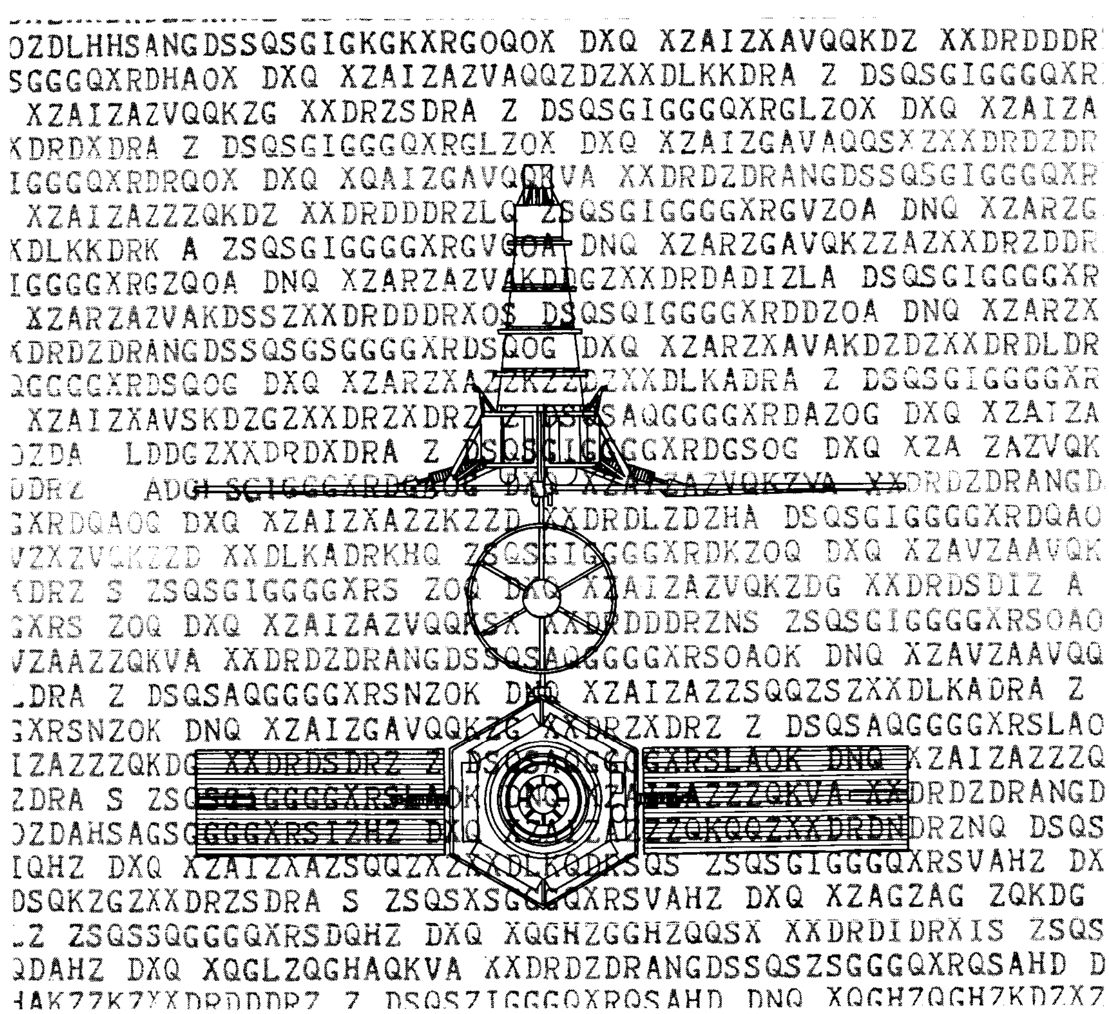
(4) The Deep Space Instrumentation Facility.

These four systems are integrated under the over-all management of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, as directed by the

Office of Space Science of NASA. The Lewis Research Center, an agency of NASA, is responsible for the Launch Vehicle System. The three remaining systems of the *Ranger* Project are under JPL management.

Approximately 65 hours after launch, the spacecraft will be about 900 miles from the Moon and falling toward it at a velocity of about 4500 miles per hour. At this point in the flight, the TV subsystem is programmed to begin viewing the lunar surface, translating the lunar scene into video data for transmission back to Earth. Ten minutes later the spacecraft, its mission completed, will impact the Moon and be destroyed.

Although weight and space limitations severely restrict the amount of video equipment that can be carried by the spacecraft, the highly developed RCA TV subsystem is capable of producing TV photographs of the Moon. These video pictures will be transmitted a distance 2000 times greater than the maximum range of commercial TV stations operating under the most favorable conditions. This photographic data, transmitted back to Earth by the spacecraft, will help to fill the urgent need for lunar topological data required for NASA's soft landing instrumented spacecraft *Surveyor*, and for the manned Moon mission, *Apollo*.



A closeup look at the lunar surface is necessary in order to prepare for future instrumented soft landings and finally the manned missions.

Our Satellite, The Moon

The Moon, our closest celestial neighbor and the object of legends and superstitions since history began, is as familiar to us as is the face of a close friend. We know the solemn beauty of the full Moon and the half comic, half frightening face of the "Man in the Moon." Poets ponder the influence of the ever-constant Moon on romance. Children speculate whether or not it is really made of green cheese. And more sober adults smile condescendingly at both of these theories. Yet very little is actually known about the Moon.

A prehistoric remnant, relatively unchanged for billions of years, the Moon may prove to be the Rosetta Stone that will unlock many of the secrets of the origin and evolution of our solar system.

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 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." [a]

Galileo first gazed at the Moon through a telescope more than 350 years ago. Since that time, however, we have seen little more of the detail of the Moon's surface than did Galileo. Our modern telescopes are better, but we still stand the same distance from the Moon and on

[a] "Galilei, Galileo"; p. 63; dialogue concerning the two chief world systems, Ptolemaic and Copernican; Translation by Stillman Drake; Foreword by Albert Einstein; University of California Press, Berkeley, California.

Photo courtesy Mt. Palomar Observatory

Figure 1. Crater Clavius and surrounding regions

the same platform—the Earth. We still must peer through the same mantle of atmosphere that hindered Galileo's viewing. That blanket of life-giving air that protects Earth life and causes the stars to twinkle so delightfully unfortunately makes the details of the Moon twinkle also.

Although the lunar surface conditions still elude us, we have 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. The action of atoms and molecules at the surface, or just under the surface of the Moon, under eon-long bombardment by undiluted solar radiation and by cosmic rays, cannot be predicted. The formation of complex macro-molecules may be possible.

Additionally, the Moon has a diameter of about 2163 miles—about one-quarter that of Earth. Because it is smaller than Earth, its gravity is much less. Standing on the surface of the Moon, one would weigh only one-sixth as much as he weighs on Earth. The density of the Moon is 3.3 times that of water, while that of Earth is 5.5. Scientists agree that the Moon's mass is about 1¼ percent of the Earth's mass. The lunar world is in a slightly elliptical orbit at an average distance of approximately 238,000 miles from Earth. The Moon requires 27⅓ days to make a complete orbit of Earth and, because its rotational period is the same, it always presents the same face toward Earth.

The Moon generates no light of its own and shines solely by reflected Sunlight or Earthlight; only 59% of its surface is visible from Earth. The Moon has no obvious effect on the climate of the Earth, but is the dominant factor in the production of tides. There is also some slight but distinct relationship between the changes of distance of the Moon from the Earth and variations in terrestrial magnetism.

Photo courtesy Lick Observatory

Figure 2. Lunar region of craters Copernicus and Eratosthanes

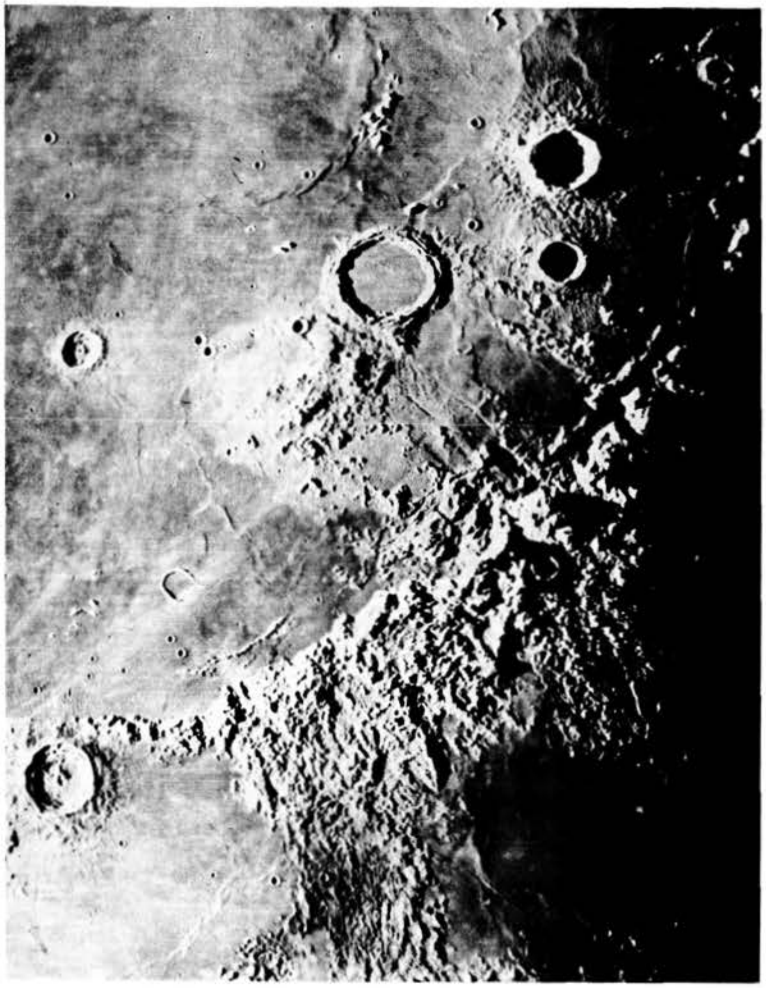


Photo courtesy Lick Observatory

Figure 3. Lunar area, southwestern margin of Mare Imbrium

Recent studies have made it appear probable that the great craters on the Moon are impact craters rather than volcanic craters (Figs. 1 and 2). It also seems that at least some of the maria (the great plains) are the direct result of impact (Fig. 3). It is not clear if the impacts acted primarily as a trigger mechanism releasing molten material (if any) from the Moon's interior, or if the melting material resulted primarily from the kinetic energy of the impacts.

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 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 to obtain a spectrogram 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. This "atmosphere" is very tenuous at best and must consist primarily of a few stray molecules of heavy inert gases. Perhaps a few light gases are in existence for a short time and immediately after a volcanic emission. Additionally, in recent months, unidentified temporary reddish areas have been sighted in other parts of the lunar surface.

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 early stages of lunar exploration will be to determine the exact nature of the Moon's surface. This will be the starting place, and eventually all the questions will be answered. The exact nature of the Moon's surface is extremely important to the basic design of both unmanned and manned lunar spacecraft; unfortunately, it is not possible to resolve these questions by looking through our telescopes.

In the photograph (Fig. 4) the Mare Imbrium—the right eye of the man in the Moon—is seen (top left). This is one of the level plains or maria. Standing out on the plain just below the outer rim of mountains is Mt. Piton. In the photograph (taken by Lick Observatory, University of California, Mt. Hamitton, California), Mt. Piton appears as a small, jagged hound's tooth. It is possible to measure heights on the Moon with surprising accuracy by measuring shadow lengths. A better understanding of the actual configuration of Mt. Piton may be obtained by considering ourselves as Moon explorers, standing on the surface of the Moon, a few miles from its base. From here it would appear as a high but gentle sloping mountain rising to about 7000 feet and stretching out more than 70,000 feet (about 13 miles). The top is so nearly level that it would be difficult to determine the highest point. Certainly, from this point of view, it looks very different from the rugged mountain it appears to be in the photograph.

In pictures of the Moon taken with the 200-inch telescope at Palomar at high magnification (Fig. 1), the smallest detail that can be seen is almost a mile across. Details smaller than that are simply unresolved and must await the actual landing of our scientific instruments on the Moon or close distance photographing of the Moon by cameras operating outside the distortion of the Earth's atmosphere.

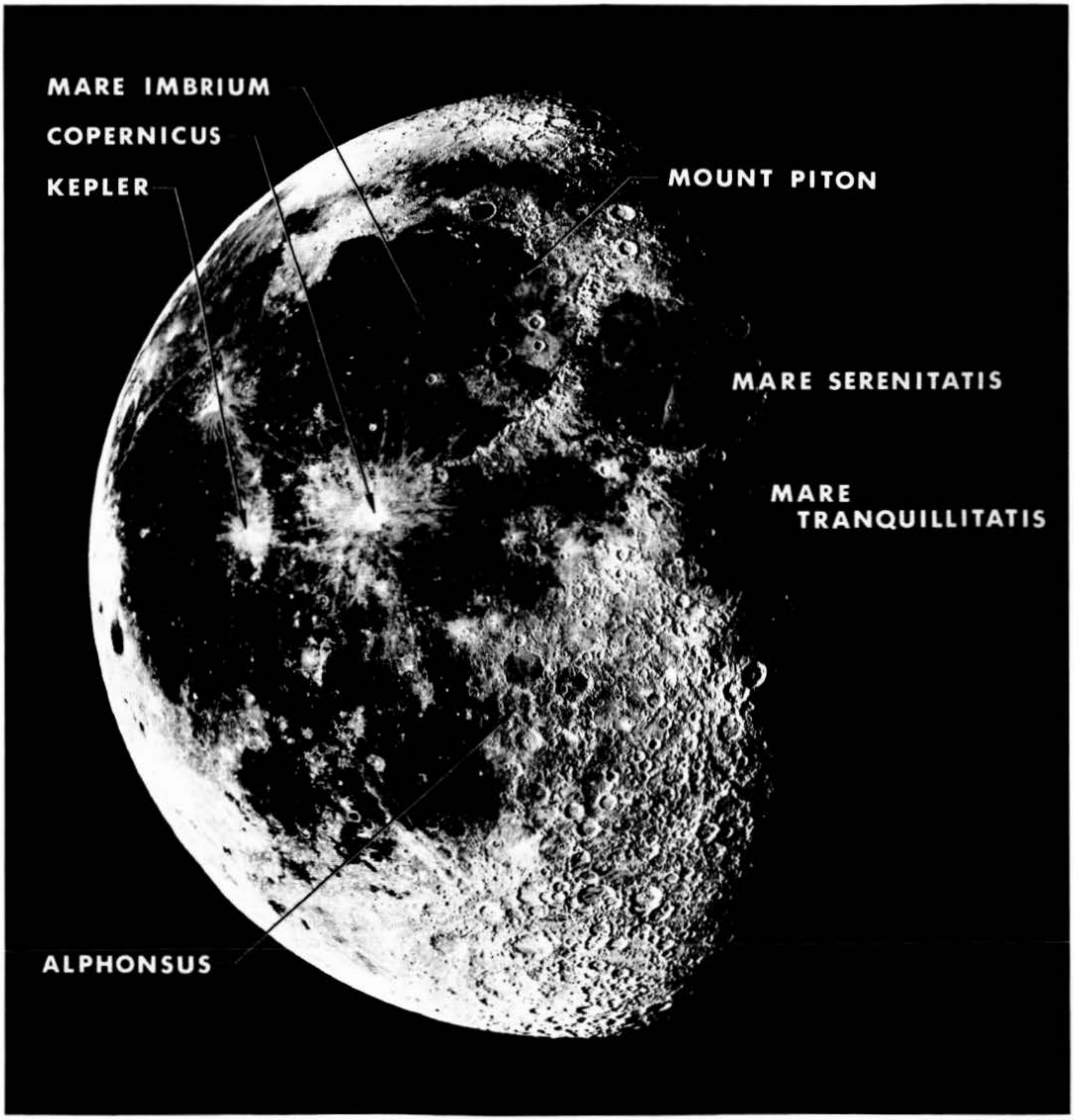


Photo courtesy Lick Observatory

Figure 4. Eastern part of the Moon

The launching problem is severe: The Moon is a most difficult target and the launch constraints are many.

The Launch Problem

The launch problem is partially illustrated in Fig. 5. It is helpful to envision the path of the spacecraft as a tunnel through which the spacecraft passes on the way to its destination. The entrance to this tunnel is actually the injection point of the spacecraft, the point at which the *Agena* booster ceases to impart velocity to the spacecraft. The entrance to this tunnel begins at a point approximately 115 miles above the Earth, is about 10 miles in diameter, and extends to the Moon. Because of the curved nature of the trajectory, the distance the spacecraft must travel is about ⅓ million miles, although the average, straight-line distance to the Moon at the launching time is approximately 238,000 miles.

Some of the factors, imposed by the nature of the solar system, that complicate the role of the launch vehicle are:

(1) The Earth is rotating on its axis, making one complete turn every 24 hours. The launch site, being located in Florida approximately 30 degrees north of the Equator, therefore turns through space at a speed of nearly 1000 miles per hour.

(2) The target, the Moon, is orbiting the Earth at a rate of approximately 2000 miles per hour.

(3) For technical reasons, the time of arrival of the spacecraft at the target must occur during the Goldstone Tracking Station view period. The time of arrival is also critically related to the illumination conditions of the lunar surface, and hence to the success of the picture-taking mission.

(4) Escape velocity can only be reached safely outside the Earth's mantle of atmosphere.

Additional constraints also arise from the fact that the launch vehicle's path over the Earth must be restricted to a corridor that would preclude any portions of the *Atlas–Agena* launch vehicle from impacting any populated areas or endangering shipping lanes. In view of these factors, the exacting role of the launch vehicle becomes more apparent.

The launch corridor is shown in Fig. 6. It extends normally from a launch azimuth of 90 to 114 degrees in a

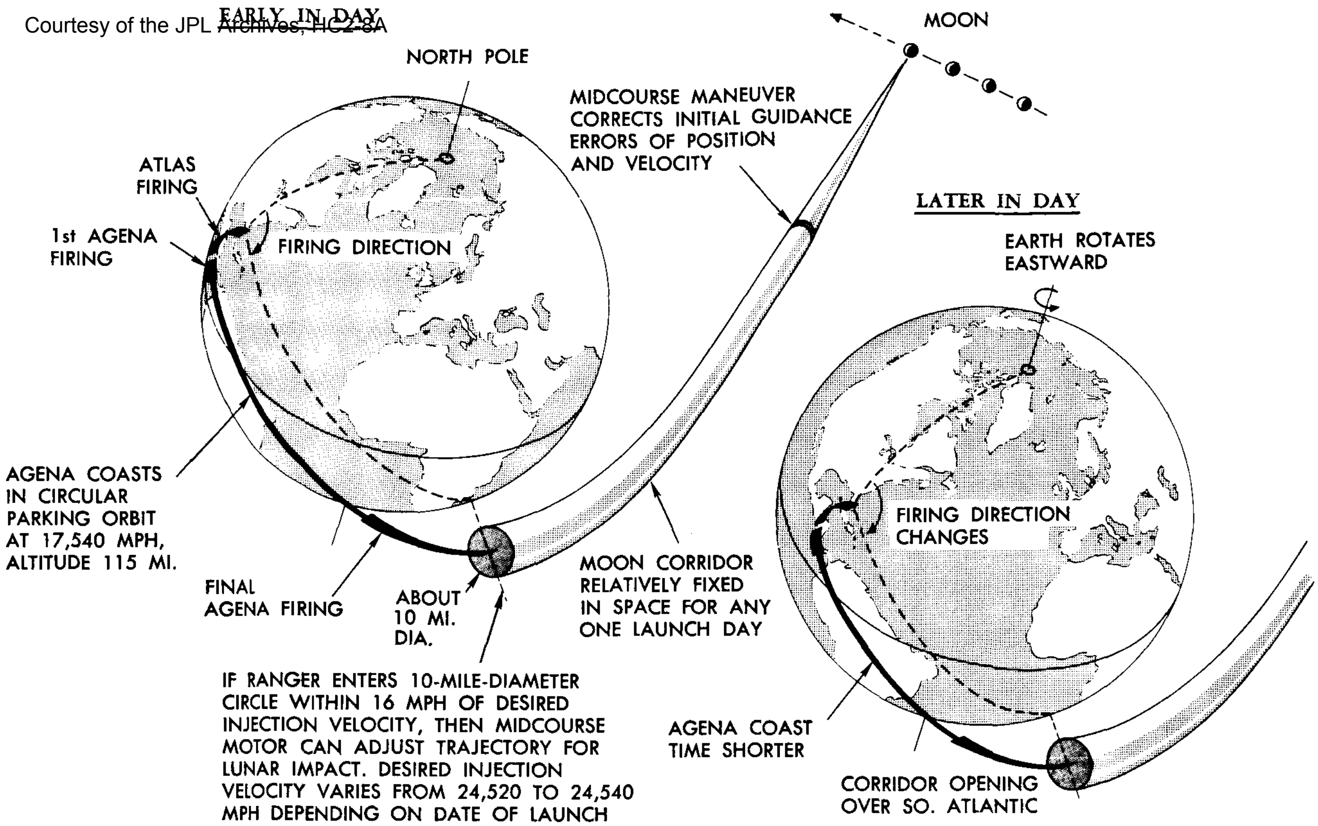


Figure 5. Typical *Ranger* launch to Moon

southeasterly direction from Cape Kennedy in Florida. The exact trajectory chosen for any particular flight depends upon the day of the month and the time of day of the launch. Therefore, as seen from the Earth, the exact location of the injection point varies as a function of launch date. Additional factors, caused by the mission objectives and the technical requirements of the spacecraft and its Earth-based support equipment, place even further restraints on the launch. All these and other pertinent factors are taken into consideration in the design and selection of the trajectory to be flown by the launch vehicle and spacecraft.

For the few consecutive days that occur during each month when the geometric relationship of the Earth, Moon, and Sun would permit a successful launch (Fig. 7), extensively detailed tabulations of the velocity, position, and acceleration necessary to put the spacecraft into orbit are computed for each day and recorded. These tabulations become the standards from which flight paths for virtually any moment of the day can be projected. The primary variables used to compensate for the changing celestial geometry are the launch azimuth and the length of time the vehicle is allowed to remain in the parking orbit. The parking orbit is an advanced technique requiring the use of a second-stage vehicle equipped with a restartable rocket engine. At the conclusion of the first burn of the *Agena B* engine, the second stage has attained sufficient velocity to orbit the Earth as a near-Earth satellite at an altitude of about 115 miles. The vehicle then coasts to a proper location over the mid-Atlantic where the rocket engine is restarted to accelerate the spacecraft to escape velocity. Accordingly, the exact azimuth of the actual launch dictates the specific set of trajectory computations used as the standard by which the normalcy of the flight is judged.

Stated in its most fundamental form, the space mission is composed of these tasks:

(1) Placing a spacecraft into a path or trajectory that will carry it to its desired destination.

(2) Tracking the spacecraft during its flight for its actual position, velocity, and direction of travel so that proper corrections to its trajectory may be made if required.

(3) Maintaining continuous two-way communications with the spacecraft in order to command operational changes if required, and receiving on the ground the data it is producing.

(4) Executing the engineering and scientific tasks through the use of instruments aboard the spacecraft.

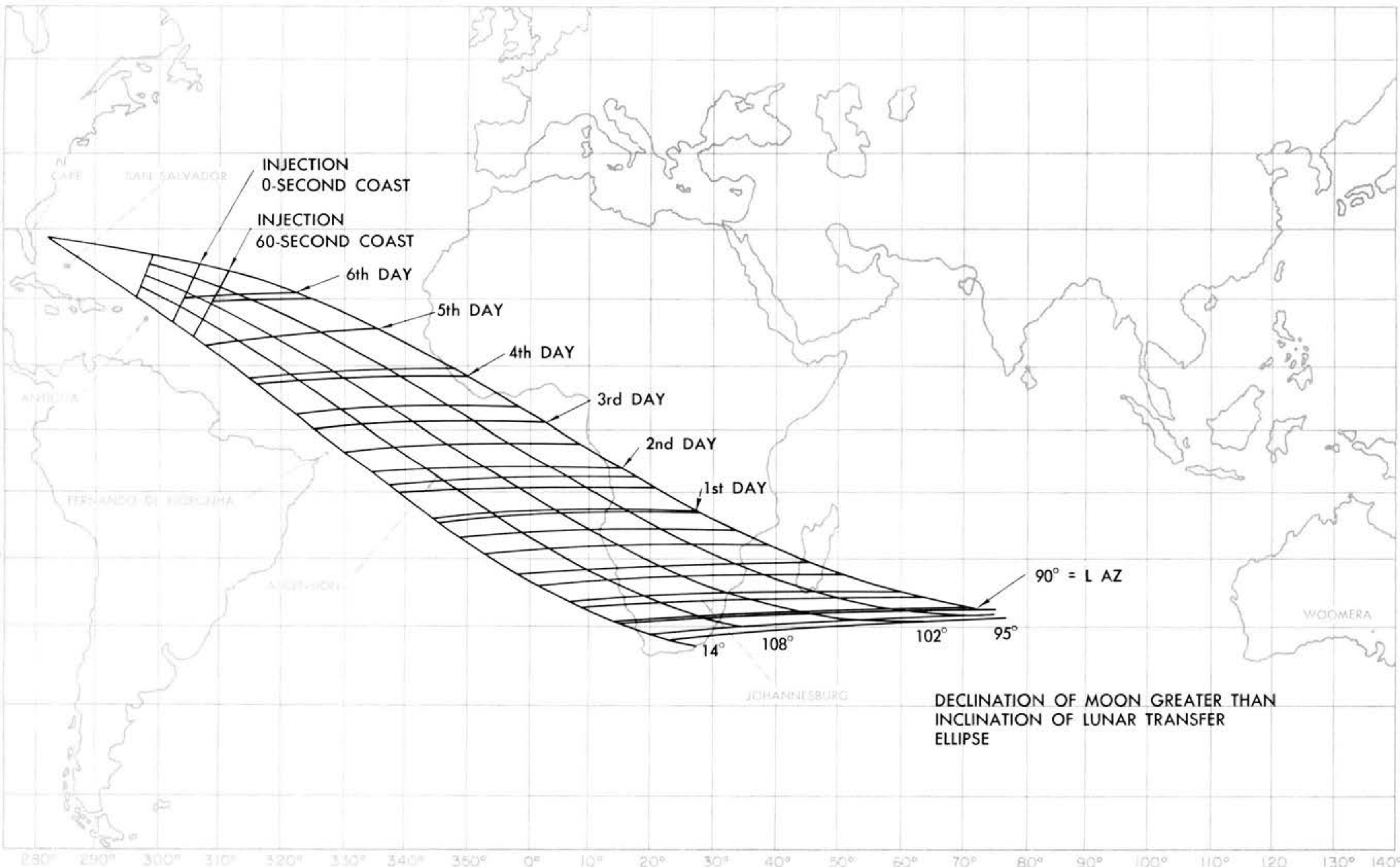


Figure 6. Launch and injection corridor *Ranger* Block III missions

Courtesy of the JPL Archives, HC2-8A

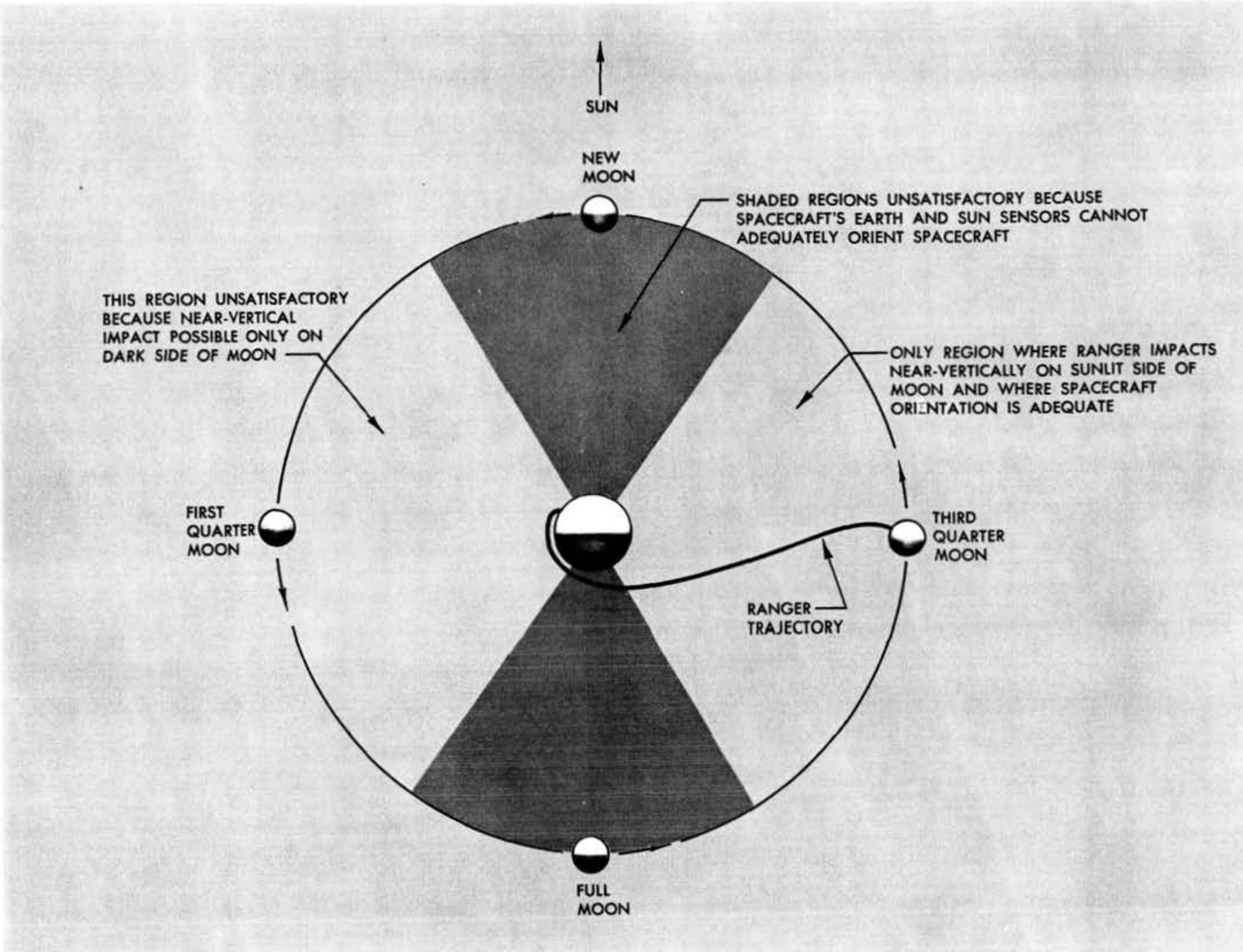


Figure 7. Trajectory limitations on *Ranger* Block III missions

Close determination of surface characteristics of the Moon is required for future instrumented soft landings and finally manned missions.

Spacecraft Description

The *Ranger* spacecraft (Fig. 8) is a basic unit capable of carrying as its passengers various types and kinds of instruments. This unit (or bus) provides power, communication, attitude control, command functions, trajectory correction, and a stabilized platform upon which the scientific instruments can be mounted. The spacecraft is designed to accomplish certain tasks during predetermined periods of the flight. These periods are:

(1) The liftoff-to-injection period, or launch mode.

(2) Earth and Sun acquisition maneuvers that place the spacecraft in cruise mode, for the period of normal flight.

(3) The midcourse maneuver to correct the flight trajectory if necessary.

(4) The terminal maneuver which orients the spacecraft to meet the requirements of the instruments.

The basic spaceframe is composed of a series of concentric hexagons constructed of aluminum and magnesium tubing and structural members. Electronic cases are attached to the six sides and a high-gain, dish-shaped antenna is hinged to the bottom. Sun sensors and attitude control jets are mounted on four of the legs of the hexagon. The midcourse motor is set inside the hexagonal structure with the rocket nozzle facing downward. The bus also includes a hat-shaped omnidirectional antenna which is mounted at the peak of the conical structure.

Two solar panels (Fig. 9) are hinged to the base of the hexagon and are folded alongside the spacecraft during launch. During the period of flight, the panels are unfolded horizontally when the spacecraft is in its space attitude. The panels provide 24.4 square feet of solar cell area which, when exposed to Sun, will deliver 200 watts of raw power to the spacecraft. There are 4896 solar cells in each panel.

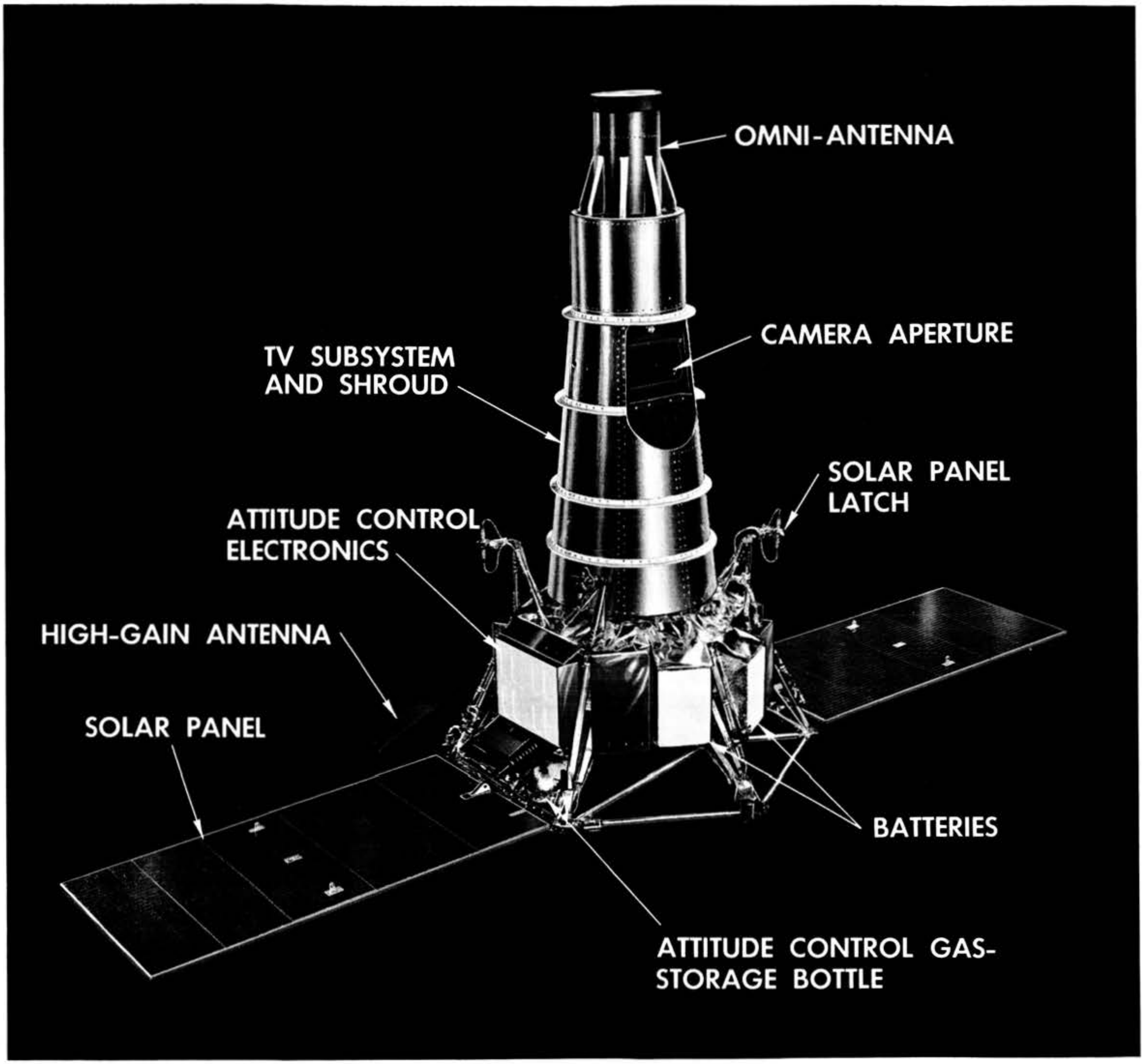


Figure 8. ***Ranger*** **spacecraft**

Prior to opening the solar panels during launch, and during the midcourse and terminal maneuvers, two silver zinc batteries provide power for the bus. The batteries each have a 9-hour lifetime and provide 26.5 volts each. Either battery is capable of providing all of the power required for launch, and midcourse and terminal maneuvers.

Weight and dimensions of the spacecraft are given in Table 1.

The six cases girdling the spacecraft (Fig. 10) house the following: case 1, central computer and sequencer (CC&S) and command subsystem; case 2, radio receiver

Table 1. *Ranger* space vehicle

Launch vehicle	*Atlas D–Agena B*
Dimensions (launch vehicle)	
Total height, with *Ranger* spacecraft, plus shroud	100 plus feet
Atlas	66 feet
Agena B	12 feet
Dimensions (*Ranger*)	
In launch position, folded	
Diameter	5 feet
Height	8.25 feet
In cruise position, panels unfolded	
Span	15 feet
Height	10.25 feet
Weight (*Ranger*)	
Structure	90.37 pounds
Solar panels	47.82 pounds
Electronics	154.36 pounds
Propulsion	45.74 pounds
Launch back-up battery	51.75 pounds
Miscellaneous equipment	37.89 pounds
Ranger bus total	427.93 pounds
TV subsystem total	375.94 pounds
Gross weight of the spacecraft	803.87 pounds

and transmitter; case 3, data encoder (telemetry); case 4, attitude control, (command switching and logic, gyros, autopilot); case 5, spacecraft launch and maneuver battery; case 6A, power booster regulator, power switching logic, and squib firing assembly; case 6B, second spacecraft launch and maneuver battery.

Two antennas are employed on the spacecraft. The low-gain, omnidirectional antenna transmits during the launch sequence and the midcourse maneuver only. It functions at all other times throughout the flight as a receiving antenna for commands radioed from Earth.

A dish-shaped, high-gain directional antenna (Fig. 11) is employed in the cruise and terminal modes. The hinged, directional antenna is equipped with a drive mechanism allowing it to be set at appropriate angles. An Earth sensor is mounted on the antenna yoke near the rim of the dish-shaped antenna to search for, and keep the antenna pointed at, Earth. During midcourse maneuver, the directional antenna is moved out of the path of the rocket exhaust, and transmission is switched to the omni-antenna.

The midcourse rocket motor (Fig. 12) is a liquid monopropellant engine weighing, with fuel and nitrogen

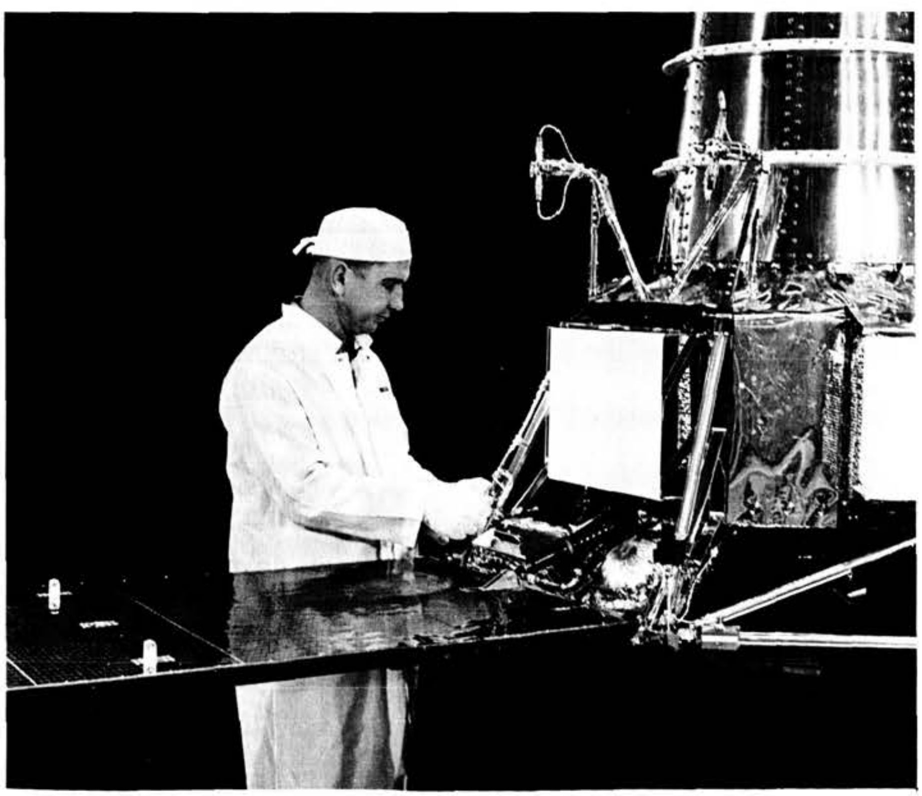


Figure 9. *Ranger* solar panel showing hinge actuator

pressure gas system, 46 pounds. Hydrazine fuel is held in a rubber bladder contained inside a doorknob-shaped container called the pressure dome. On the command to fire, nitrogen, under 300 pounds of pressure per square inch, is admitted inside the pressure dome and squeezes the rubber bladder containing the fuel.

The hydrazine is thus forced into the combustion chamber. A small quantity of oxidizer is used to initiate combustion, and a catalyst to maintain combustion. The starting fluid used, in this case nitrogen tetroxide, is admitted into the combustion chamber by means of a pressurized cartridge. The introduction of the nitrogen tetroxide causes ignition, and the burning in the combustion chamber is maintained by the catalyst—aluminum oxide pellets stored in the chamber. Burning stops when the valves turn off nitrogen pressure and fuel flow.

At the bottom of the nozzle of the midcourse motor are four jet vanes which protrude into the rocket exhaust for attitude control of the spacecraft during the midcourse motor burn. The vanes are controlled by an autopilot linked to gyros.

The midcourse motor is capable of firing in bursts as short as 50 milliseconds, and can alter velocity in any direction by as little as 4 inches per second or as much as 190 feet per second. It has a thrust of 50 pounds for a burning time of more than 90 seconds.

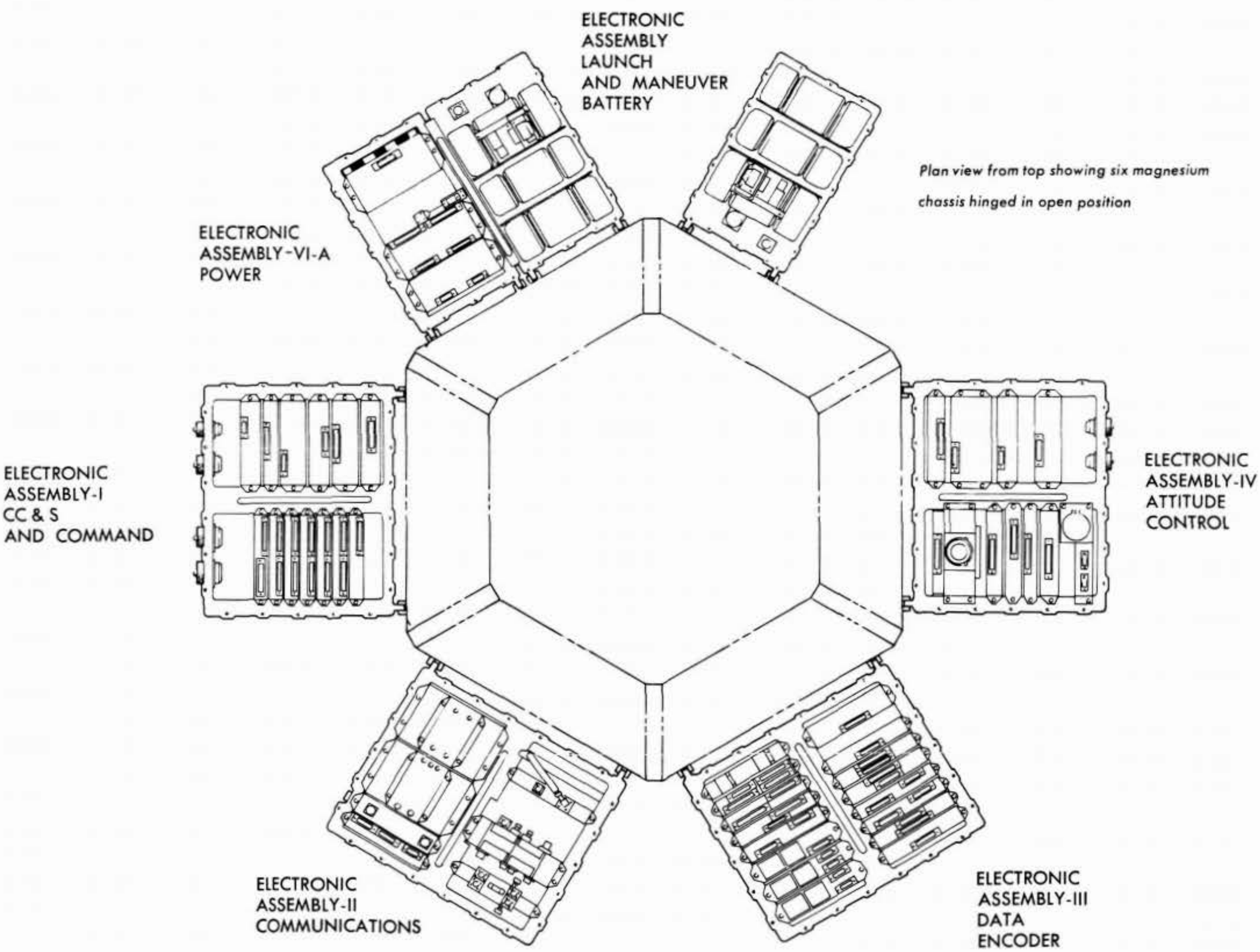


Figure 10. Subsystem cases on spacecraft—hexagonal structure

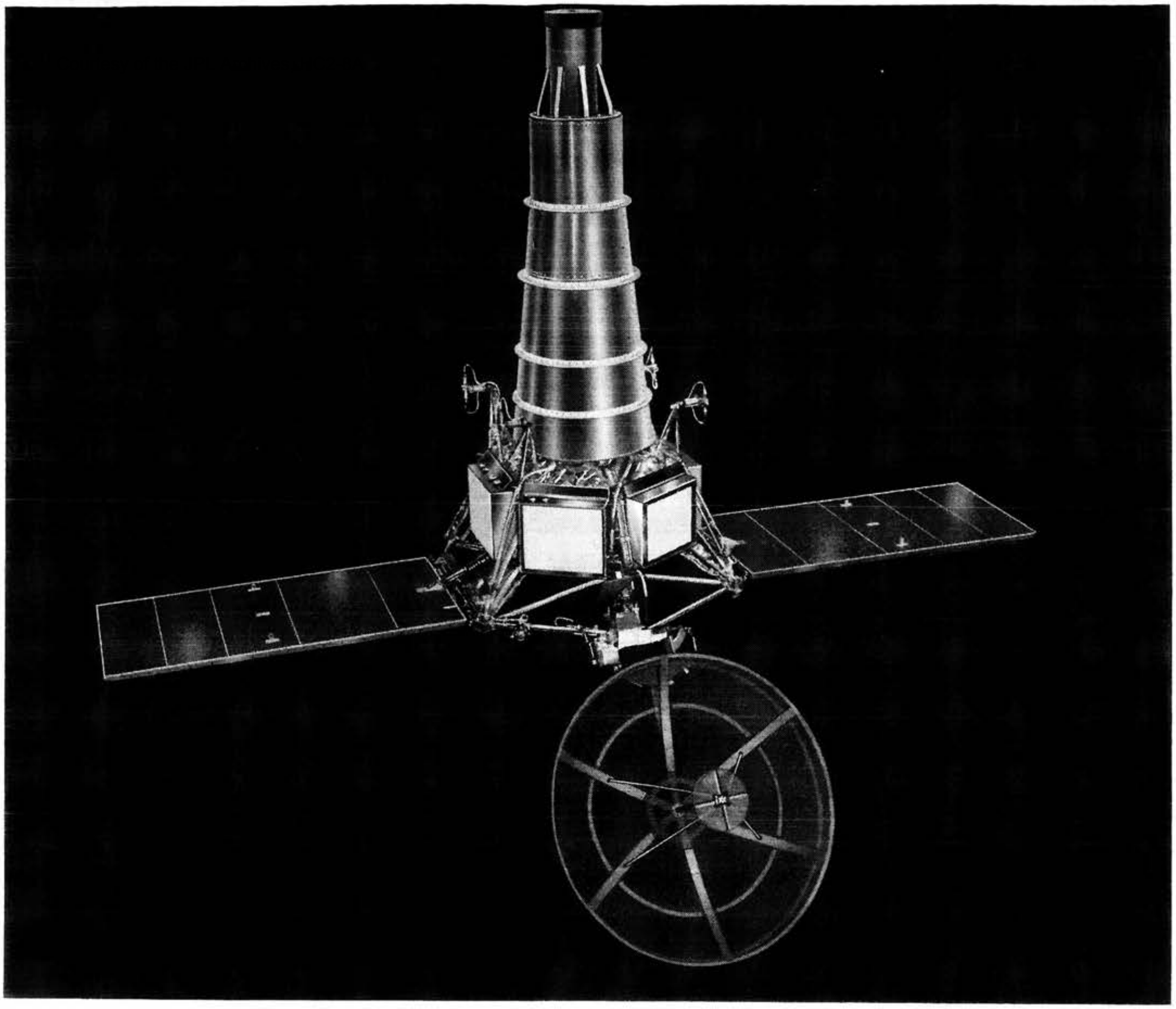


Figure 11. High-gain directional antenna

Aboard the spacecraft are three radios: the 3-watt receiver–transmitter in the bus and two 60-watt transmitters. These transmit, during terminal maneuver, the images recorded by the six television cameras. One transmitter handles the two full-scan (wide-angle) cameras; the second transmits data from the four partial-scan (narrow-angle) cameras.

During the cruise portion of the flight, before the cameras are switched on for the terminal maneuver, the bus transmitter transmits telemetry, (engineering data) for both bus and TV subsystem.

A total of 110 engineering measurements (temperatures, voltages, pressures) of the spacecraft are telemetered back to Earth during the cruise portion of the

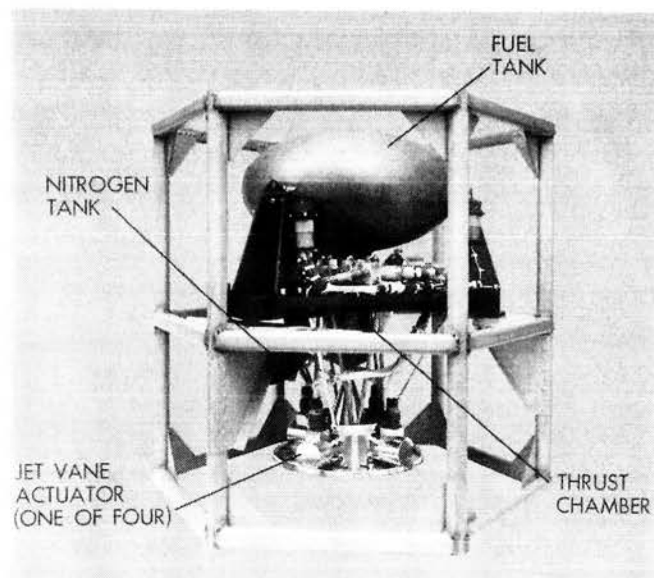


Figure 12. Midcourse rocket motor

The planes of movement through which the spacecraft passes are illustrated below. The attitude of the spacecraft is established and maintained by commands executed by the attitude control system in conjunction with other systems of the spacecraft. The attitude control system regulates the movements of the spacecraft in these three planes and accomplishes these movements by imparting small amounts of thrust to the spacecraft bus by the discharge of nitrogen gas from the 12 cold-gas jets positioned on and about the hexagonal frame of the spacecraft. The desired posture of the spacecraft is dictated by its spatial relationship with the Sun and Earth. It must keep its solar panels facing the Sun for solar power and the high-gain antenna facing Earth for communication. The Sun and Earth sensors, part of the attitude control system, continuously generate signals which are combined with information from the rate gyros of the autopilots. The latter supply the information defining the rate of movement. This combined information is translated by the attitude control system into commands to the appropriate cold-gas jets or combination of jets. This cycle is repeated until the desired attitude of the spacecraft is established and subsequently continues to function maintaining this posture.

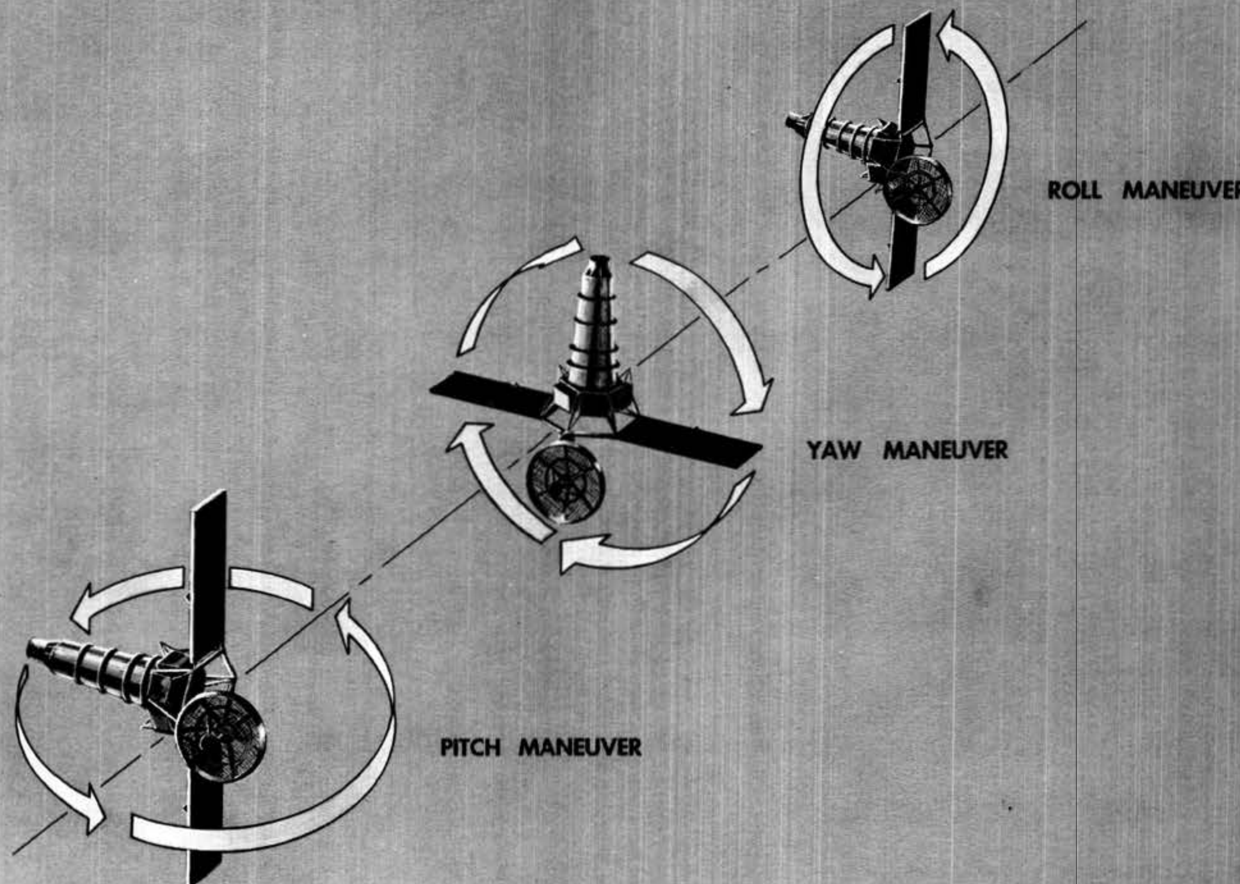


Figure 13. Attitude controlled movements of spacecraft

flight. This includes 15 data points on the television subsystem. During terminal maneuver, with the television turned on, the radios transmit additional engineering data on the TV subsystem mixed with signals representing the television images. During the terminal maneuver, 90 additional engineering measurements on the spacecraft are transmitted.

The communications system for the bus includes data encoders that translate the engineering measurements into analog values for transmission to Earth; and a detector and a decoder, in the command subsystem, that translate incoming commands to the spacecraft from a binary form into electrical impulses. Commands radioed to the spacecraft are routed to the proper destination by the command subsystem. A real-time command, (RTC) from Earth actuates the designated relay within the command decoder, thus executing the command. Stored commands are relayed to the CC&S in serial binary form to be held and acted upon at a later time.

The television subsystem includes separate encoders to condition the television images for transmission in analog form.

Stabilization and maneuvering of the spacecraft in pitch, yaw, and roll (Fig. 13) are provided by 12 cold gas jets mounted in six locations and fed by two titanium bottles containing a total of 5 pounds of nitrogen gas pressurized at 3500 pounds per square inch. The jets are linked by logic circuitry to three gyros in the attitude control subsystem, to the Earth sensor on the directional antenna, and to six Sun sensors mounted on the spacecraft frame and on the backs of the two solar panels. There are two complete gas jet systems of six jets and one bottle each. Either system can handle the mission requirements in the event the other system fails.

The four primary Sun sensors (Fig. 14) are mounted on four of the six legs of the hexagon; the two secondary sensors are mounted on the backs of the solar panels. These are light-sensitive diodes which inform the attitude control system when they see the Sun. The attitude control system responds to these signals by turning the spacecraft and pointing the longitudinal or roll axis toward the Sun. Torqueing of the spacecraft for these maneuvers is provided by the cold gas jets fed by the nitrogen gas regulated to 15 pounds per square inch pressure.

Computation and the issuance of commands are the functions of the digital CC&S. All in-flight events performed by the spacecraft are contained in three CC&S sequences. The launch sequence controls events from launch through the cruise mode. The midcourse propulsion sequence controls the midcourse trajectory correction maneuver. The terminal sequence provides required commands as *Ranger* nears the Moon.

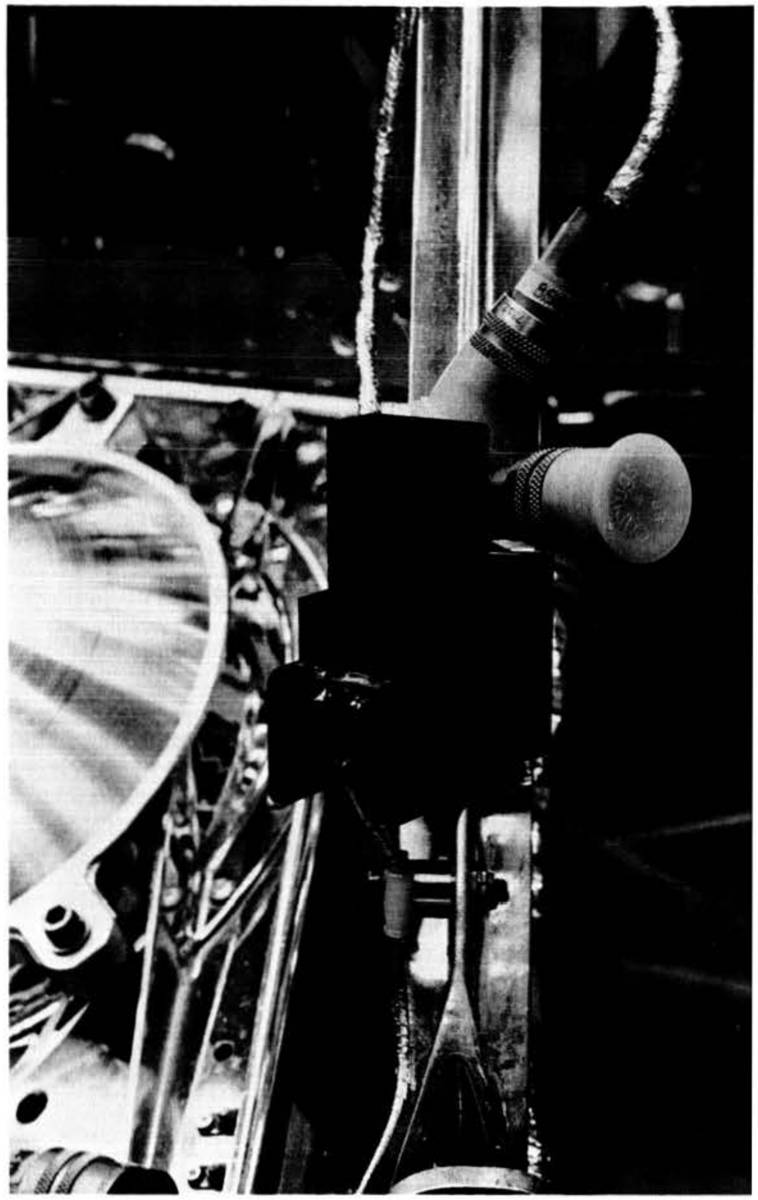


Figure 14. Sun sensor

The CC&S provides the basic timing for the spacecraft subsystems. This time base is supplied by a crystal controlled oscillator in the CC&S operating at 307.2 kilocycles. This is divided down to 38.4 kilocycles for timing in the power subsystem, and divided down again for use by other subsystems to 2.4 kilocycles, 400 cycles,

Courtesy of the JPL Archives, HC2-8A

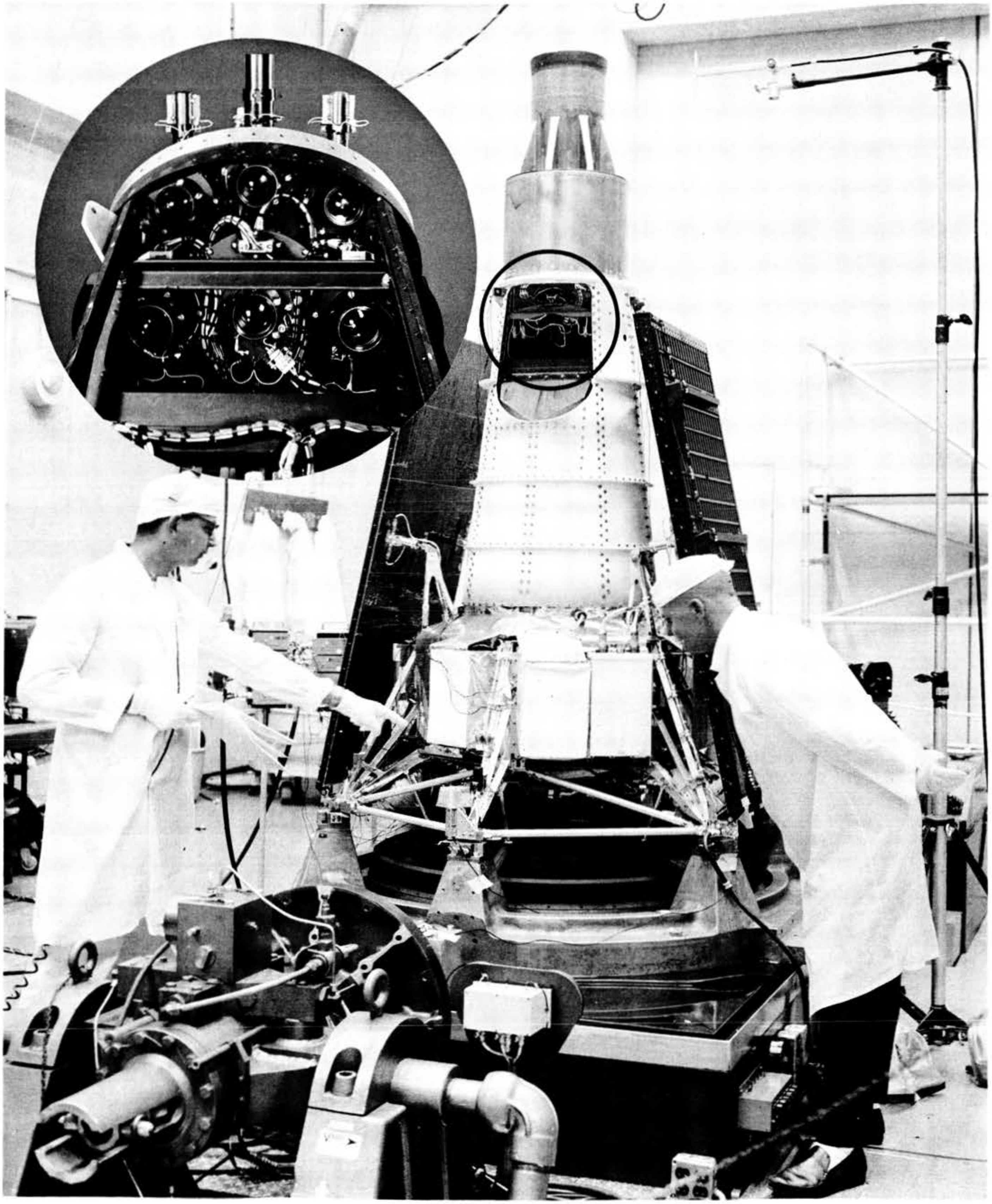


Figure 15. *Ranger* TV subsystem

and 25 pulses per second. The control oscillator provides the basic counting rate for the CC&S to determine issuance of commands at the right time.

The six TV cameras (Fig. 15) are housed in a riveted aluminum structure with a removable conical cover. The cover is a load bearing part of the structure and provides a thermal control function. Fins are attached to the cover to intercept the Sun's rays to provide adequate heat during cruise. The entire cover radiates heat during the 15 minutes of the terminal maneuver when the television subsystem is operating.

Instructions radioed to the spacecraft for the terminal maneuver are computed to orient the spacecraft to point the cameras downward as *Ranger* drops toward the Moon's surface. The cameras' line of sight is nominally down the descent path. To achieve this, the spacecraft will descend to the Moon's surface tilted at an angle of 38 degrees relative to the descent path.

Since the exact light level on the Moon is unknown, certain lighting condition assumptions, based on the best available information, must be made. The cameras are adjusted to cover as broad a range of lighting conditions as is feasible. A successful photographic mission will provide more exact data on lunar lighting for finer camera adjustment for use on later missions.

The 375-pound television system was designed for the *Ranger* by RCA's Astro-Electronics Division, Princeton, New Jersey.

As the *Ranger* approaches the Moon, it will take about 3000 television pictures of a selected portion of the surface before it crashes at 6000 miles per hour. The first of these pictures, to be taken at a distance of about 900 miles from the Moon, will be roughly comparable in resolution to those taken by large telescopes on Earth. As the spacecraft descends upon the Moon, the pictures improve in quality and resolution. The last few pictures taken, those taken just before the *Ranger* crashes, may distinguish objects that are no larger than an automobile.

The system consists of two wide-angle and four narrow-angle television cameras, camera sequencer, a video combiner, telemetry system, transmitters, and power supplies.

Of the two wide-angle cameras (Fig. 16), one has a 1-inch lens with a speed of *f*/1 and a field of 25 degrees. The other camera has a 3-inch, *f*/2 lens with a field of 8.4 degrees. Of the four narrow-angle cameras (Fig. 17), two have 3-inch, *f*/2 lenses with 2.1-degree fields of view, while the others have 1-inch, *f*/1 lenses with 6.3-degree fields. Both wide- and narrow-angle cameras have a fixed focus, but are able to take pictures from about 900 miles to about ⅓ mile from the Moon's surface.

All cameras have high-quality lenses with five elements and metallic focal plane or slit type shutters. This shutter is not cocked as in conventional cameras, but moves from one side of the lens to the other each time a picture is taken. Shutter speed of the wide-angle cameras is 1/200 second, and for the narrow-angle, 1/500 second.

One reason for having several cameras with different lens apertures is that the lighting conditions on the Moon can not be determined from Earth. The different lenses provide greater exposure latitude. They are set to take pictures from about 30 to 2500 foot-lamberts. This corresponds roughly to lighting conditions on Earth (on an average day) from high noon to about dusk.

Behind each of the cameras is a vidicon tube 1 inch in diameter and 4.5 inches long. The inside of the face plate of the tubes is coated with a photoconductive material that acts in much the same way as tubes in commercial television cameras. When a picture is taken, the light and dark areas form on the face plate an image of what the lens gathered as the shutter was snapped. This image is rapidly scanned by a beam of electrons. The beam is capable of differentiating light and dark areas by their electrical resistance (high resistance, a light area; low resistance, a dark area).

The image projected on the face plate of the wide-angle cameras is 0.44 inch square, while the narrow-angle camera vidicon face plates use only an 0.11 inch square. The wide-angle camera pictures are scanned 800 times by the electron beam but, because they occupy a smaller area, the narrow-angle cameras are scanned only 200 times.

The scan lines, each containing information about some part of the picture, are converted into an electrical signal. They are sent through the camera amplifier where they are amplified 1000 times.

Once amplified, the signal is sent to one of two video combiners in the TV subsystem. There is one video combiner each for the wide- and narrow-angle cameras. They combine sequentially the output of the cameras to which they are mated. The output of the video combiners are then converted to a frequency-modulated signal and sent to one of the two 60-watt transmitters. One transmitter sends pictures to Earth from the wide-angle cameras on 959.52 megacycles; the narrow-angle pictures are sent on 960.58 megacycles.

Figure 16. Wide-angle camera of TV system

Figure 17. Narrow-angle camera of TV system

The TV system also includes two batteries, one for each channel. Each battery weighs 43 pounds. They are made of 22 sealed silver zinc oxide cells and provide about 33 volts. During the 10-minute operation, the wide-angle channel will use about 4.0 ampere-hours of power while the narrow-angle channel will use 4.1 ampere-hours. The total power capacity is 40 ampere-hours.

The requirement is two-way communications from launch to impact. The data handling system is geared to provide operational information as needed, so that engineers will be in constant command of the situation.

Space Flight Operations

Clever as they may seem, spacecraft, like children and modern electronic computers, must still be told what to do, and sometimes when (Fig. 18). The Space Flight Operations System and the Deep Space Instrumentation Facility perform this function. However, the problem of keeping an eye (or more appropriately, an ear) on an out-of-this-world spacecraft requires complicated hearing aids, extremely long telephone lines, surface radio communications, difficult but fast computations, and accurate decisions.

The hearing aids are the paraboloidal dish antennas and their radio receivers located at the various ground tracking stations (Fig. 19). The telephone lines and surface radio communications are, of course, not connected to the spacecraft, but tie together the various ground installations around the world and keep them in constant contact with the operational headquarters in Pasadena, California. The fast computations are made by modern electronic computers, but the accurate decisions must still be made by humans—the scientists and engineers who control the operation.

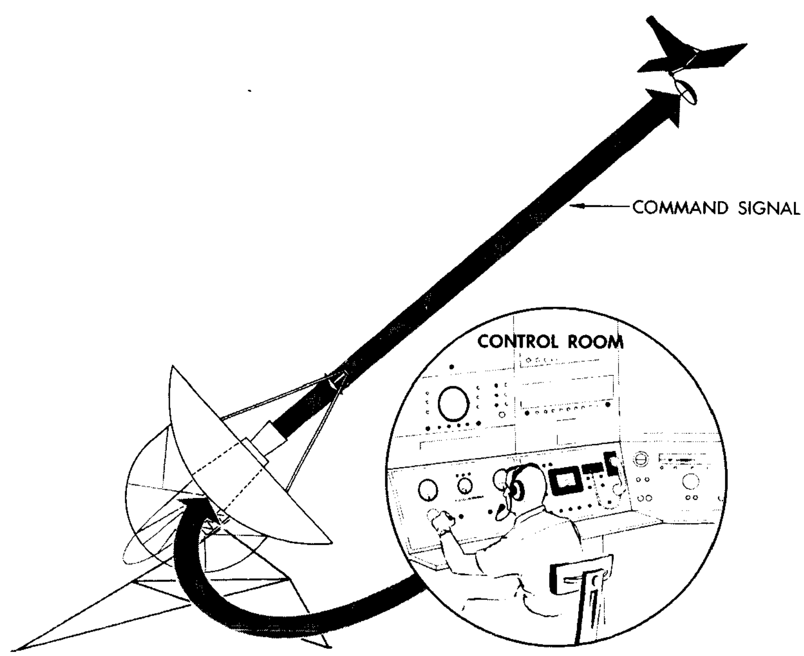


Figure 18. ***Ranger*** **command transmission**

Courtesy of the JPL Archives, HC2-8A

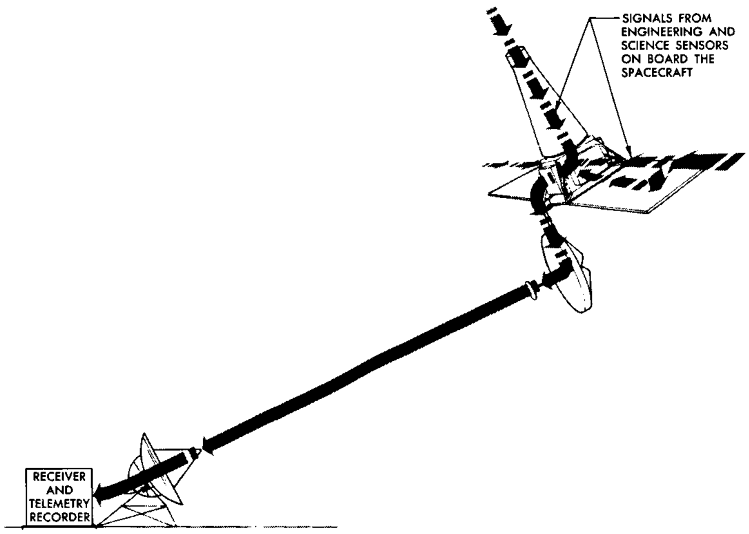


Figure 19. Ground station listening facilities

Because the Earth is a rotating prolate spheroid rather than a stationary flat plane, certain obstacles are introduced into the problem of maintaining 24-hour contact with a cislunar *Ranger*. The prolateness is of very little consequence, but the rotating requires the operation of at least three deep space tracking and communications stations, located approximately 120 degrees apart, at Johannesburg, South Africa; Woomera, Australia; and Goldstone, California (Table 2).

This is not the beginning or the end of the problem, however. Before escaping the Earth, the *Ranger* spends some very crucial minutes in initial launch ascent and low Earth orbit. Tracking and radio acquisition during these periods require two additional Earth stations. The first is a Spacecraft Monitoring Station located at Cape Kennedy and used both for prelaunch checkout of the spacecraft system and early telemetry from above the launch pad to the Cape horizon. A second station, which is the Mobile Tracking Station, is located near the Johannesburg Station in South Africa and provides for early tracking, while the *Agena* stage and *Ranger* are

Table 2. DSIF capabilities and characteristics

Characteristic	Spacecraft Monitoring Station	Mobile Tracking Station	Goldstone Pioneer Station	Goldstone Echo Station	Woomera Station, Australia	Johannesburg Station, South Africa
Antenna size	6-foot (Az–El) (no angle data)	10-foot (Az–El)	85-foot Polar (HA–Dec)	85-foot (Polar (HA–Dec)	85-foot Polar (HA–Dec)	85-foot Polar (HA–Dec)
Maximum angular rate	Manually operated	20 degrees per second in both axes	0.7 degree per second in both axes	0.7 degree per second in both axes	0.7 degree per second in both axes	0.7 degree per second in both axes
Antenna gain (960 Mc)						
Tracking feed	—	23.5 ±0.2 decibels	—	—	43.7 ±0.9 decibels	43.7 ±0.9 decibels
Horn feed	20.5 decibels	—	45.7 ±0.8 decibels	45.7 ± 0.8 decibels	—	—
Transmitter power	—	25 watts	—	200 watts (50-watt backup)	200 watts	200 watts
Data transmission						
Angles–doppler	—	Near-real time	Near-real time[b]	Near-real time[b]	Near-real time	Near-real time
Telemetry	Real time[a]	None	Record only	Near-real-time Real time[a]	Near-real-time Real time[a]	Near-real-time Real time[a]
Decommutated telemetry	No	No	No	Yes	Yes	Yes
Command capability	No	No	No	Yes	Yes	Yes

[a] Sent to the Telemetry Processing Station (TPS) via wide-band telephone line.
[b] Angle data not the result of autotrack operation.

still in Earth orbit. Initial acquisition of the high-velocity orbiting vehicle demands a greater antenna beamwidth and angular tracking rate than is available in the large 85-foot-diameter antenna of the Johannesburg Station. The 10-foot-diameter dish of the Mobile Tracking Station has a beamwidth of 7 degrees and an angular tracking rate of 20 degrees per second, compared to the 85-foot antenna values of (approximately) 0.8 and 0.7 degree per second, respectively.

No fast computations or accurate decisions can be accomplished unless the received telemetry data and generated tracking data can be quickly and accurately relayed to the computing and command decision facilities. This is done by voice and wideband (for analog data) telephone lines, teletype lines, and radio teletype.

Except for most voice communications the data, as they are received at the computing and command decision point, are in a form that can be interpreted by machines but by very few men. Even before the computers can perform their function, the language of the teletype line data must be translated into a format suitable for computer digestion. After initial processing by the Telemetry Processing Station, certain data are available for direct readout by operational personnel.

All analog and teletype data coming from the tracking stations finds its way through the big digital computer of the JPL Central Computing Facility. During the *Ranger's* journey to the Moon, it is the function of the Central Computing Facility to:

(1) Calculate the spacecraft transfer orbit from tracking data and generate pointing and prediction information for the tracking antennas.

(2) Process in near-real-time the engineering telemetry data.

(3) Generate command information for spacecraft midcourse and terminal maneuvers (if required).

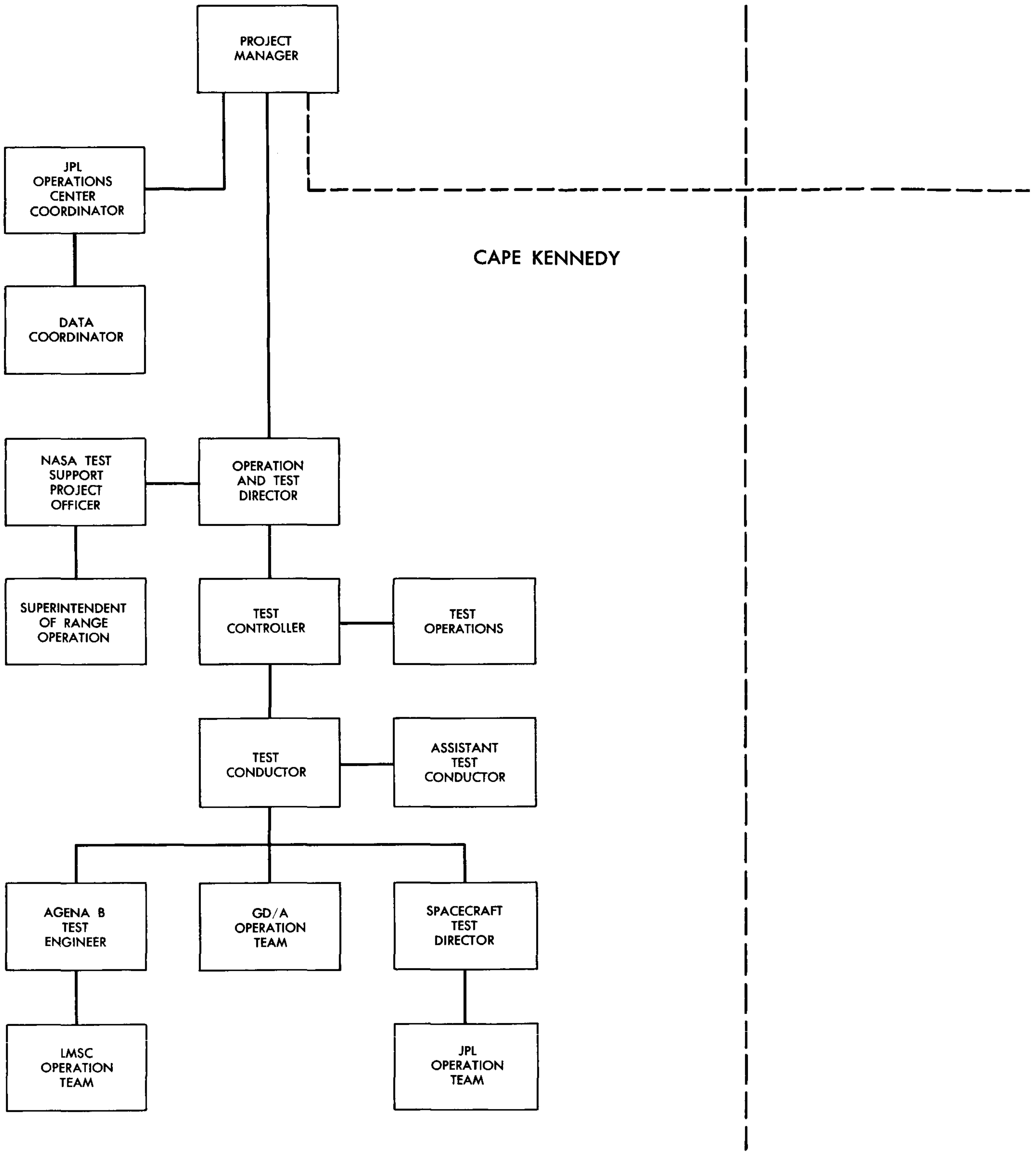
When and if it becomes necessary to command the *Ranger*, the engineers in charge of the operations must make the decision. How the decision-making process is implemented is best illustrated by the *Ranger* mission organizational structure (Fig. 20). At the head of the organization is the Project Manager who has the responsibility and authority for development and operation of the mission. Serving the Project Manager directly are the Space Flight Operations Director at JPL, and the Operations Center Coordinator at the Cape. It is the responsibility of the Space Flight Operations Director to make appropriate decisions to assure success of the mission in the absence of the Project Manager.

At the very base of the operational decision-making process are three specialized technical groups:

(1) *The Spacecraft Data Analysis Team.* It is the responsibility of this group to determine, and to keep the Space Flight Operations Director informed of, the status and performance of the spacecraft in flight in accordance with established procedures. This group recommends the use of real-time commands to improve the performance of the spacecraft in the event of a nonstandard mode of operation, and to provide such spacecraft performance information as may be required by other operational areas to perform their assigned tasks and functions.

(2) *Flight Path Analysis and Command.* It is the responsibility of this group to evaluate and use the tracking data (as well as the Spacecraft Data Analysis Team's evaluation of pertinent telemetry data) in order to determine the actual trajectory and attitude of the spacecraft during flight. From such data, this group supplies the tracking stations with acquisition and prediction information, and supplies the Space Flight Operations Director with the necessary command information for the midcourse and terminal maneuvers (if required).

(3) *Space Science Analysis and Command.* It is the responsibility of this group to control the flow of data related to the scientific experiment during the interval between its receipt from the tracking station and its transmission to the appropriate scientists. This group supplies recommendations as to the effect of various maneuver possibilities on the scientific experiment. Any analysis or inflight evaluation of the scientific data will be supplied by this group.


PROJECT MANAGER
JPL OPERATIONS CENTER COORDINATOR
DATA COORDINATOR
CAPE KENNEDY
NASA TEST SUPPORT PROJECT OFFICER
OPERATION AND TEST DIRECTOR
SUPERINTENDENT OF RANGE OPERATION
TEST CONTROLLER
TEST OPERATIONS
TEST CONDUCTOR
ASSISTANT TEST CONDUCTOR
AGENA B TEST ENGINEER
GD/A OPERATION TEAM
SPACECRAFT TEST DIRECTOR
LMSC OPERATION TEAM
JPL OPERATION TEAM

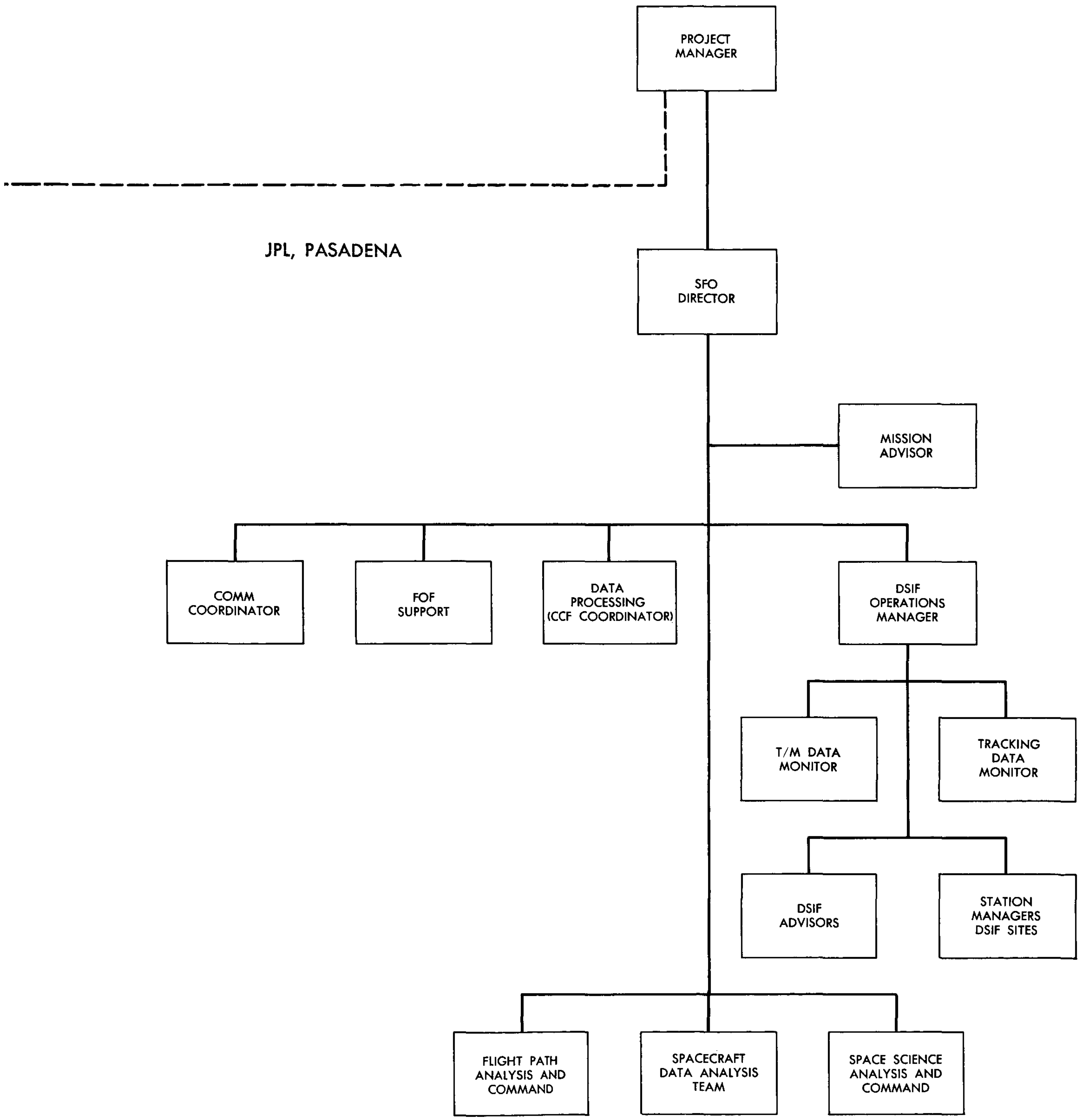
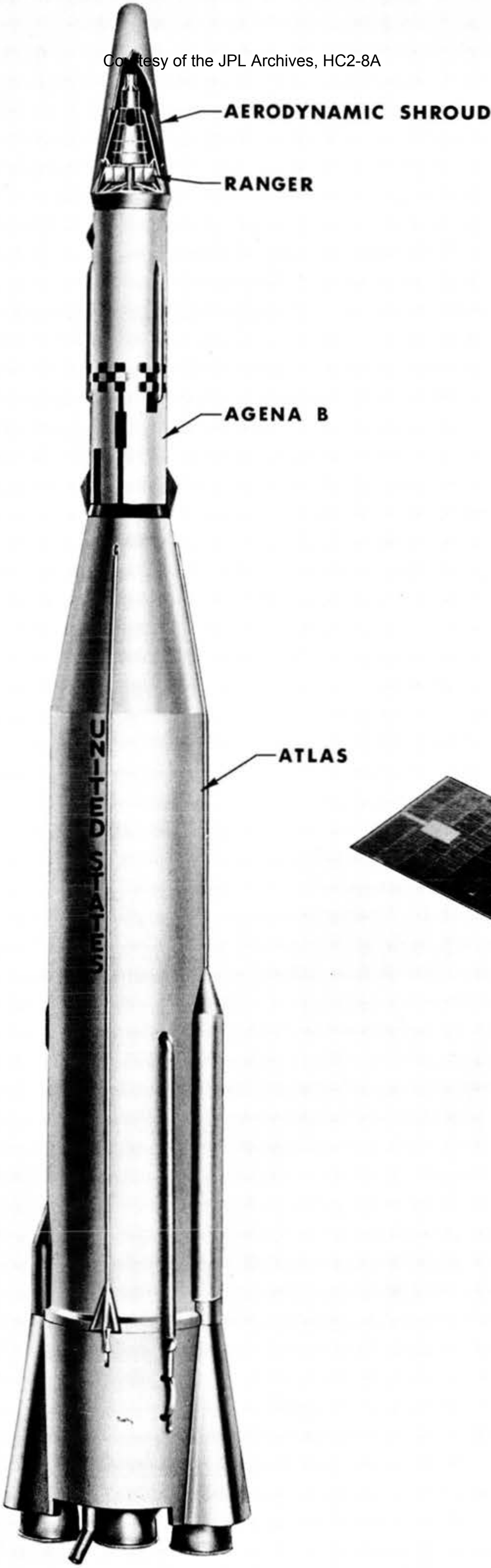


Figure 20. *Ranger* mission organization

Courtesy of the JPL Archives, HC2-8A



Similar to the famous Mariner, the Ranger spacecraft is designed to operate reliably in the environment of space. The mission is simple: Go out from Earth, deliver cameras over the lunar surface, and receive their pictures back on Earth.

Mission Description

Flight Through Injection

The launch vehicle, *Atlas D*, will boost the *Ranger* spacecraft to an altitude of 115 statute miles. During this launch phase, the *Ranger* spacecraft is protected against aerodynamic heating by a shroud which is jettisoned by spring-loaded bolts just prior to separation of the *Atlas* from the *Agena* (approximately 5 minutes after liftoff). As shown in Fig. 21, the *Atlas* booster separates from the *Agena* and the *Agena* pitches down from an attitude of nearly 15 degrees above, to almost level with, the Earth's horizon. Its engine fires and burns for approximately 2½ minutes to accelerate it and the spacecraft to an orbital speed of 17,540 miles per hour.

The *Agena* and *Ranger* then coast in the parking orbit over the Atlantic Ocean. When they reach a preselected point, the *Agena* engine fires for a second time. At the conclusion of this second burn, the *Agena* and spacecraft are injected into a lunar flight path at a velocity sufficient for their escape from Earth. The second firing accelerates the spacecraft to approximately 24,500 miles per hour. The injection point and the Moon trajectory are illustrated in Fig. 22. Following injection, spring-loaded explosive bolts are fired to separate the *Agena* from the spacecraft. Fig. 23 shows the *Agena* as it performs a 180-degree turn and a retro maneuver to remove it from the spacecraft trajectory. Propulsion for the retro maneuver is provided by a small, solid-fuel rocket motor. This maneuver ensures that the *Agena* will not impact the Moon and that it will not be in a position to reflect light that could confuse the *Ranger*'s optical sensors and cause them to mistake the *Agena* for the Earth.

The spacecraft's separation from the *Agena* automatically starts the *Ranger*'s mechanical back-up timer and TV back-up clock and releases the CC&S for issuance of flight commands. Prior to this point, the CC&S is partially inhibited to ensure that flight commands will not be given inadvertently during the launch phase.

The CC&S gives its first command, 23 minutes after launch, ordering the *Ranger* transmitter to full 3-watt power which, until this time, had been kept at reduced power of about 1.1 watts. This is necessary because high-voltage devices can arc over and damage themselves while passing through a critical Earth altitude zone between 150,000 and 250,000 feet.

Sun Acquisition

Approximately 60 minutes after launch, the CC&S initiates the Sun acquisition sequence commencing with an order to deploy the solar panels. Explosive pin pullers holding the solar panels in their launch position are detonated allowing the spring-loaded solar panels to open and assume their cruise position.

After the solar panels are deployed, the CC&S activates the attitude control system. Separation from the *Agena* may have caused the *Ranger* to tumble in a random manner about its pitch and yaw axes. The stabilization and orientation of the spacecraft required for Sun acquisition is accomplished in two stages.

During the first stage, gross movements of the spacecraft are 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 have been dampened to the extent that its longitudinal axis is consistently pointing in the general direction of the Sun, the second stage begins. In this stage, the final pointing

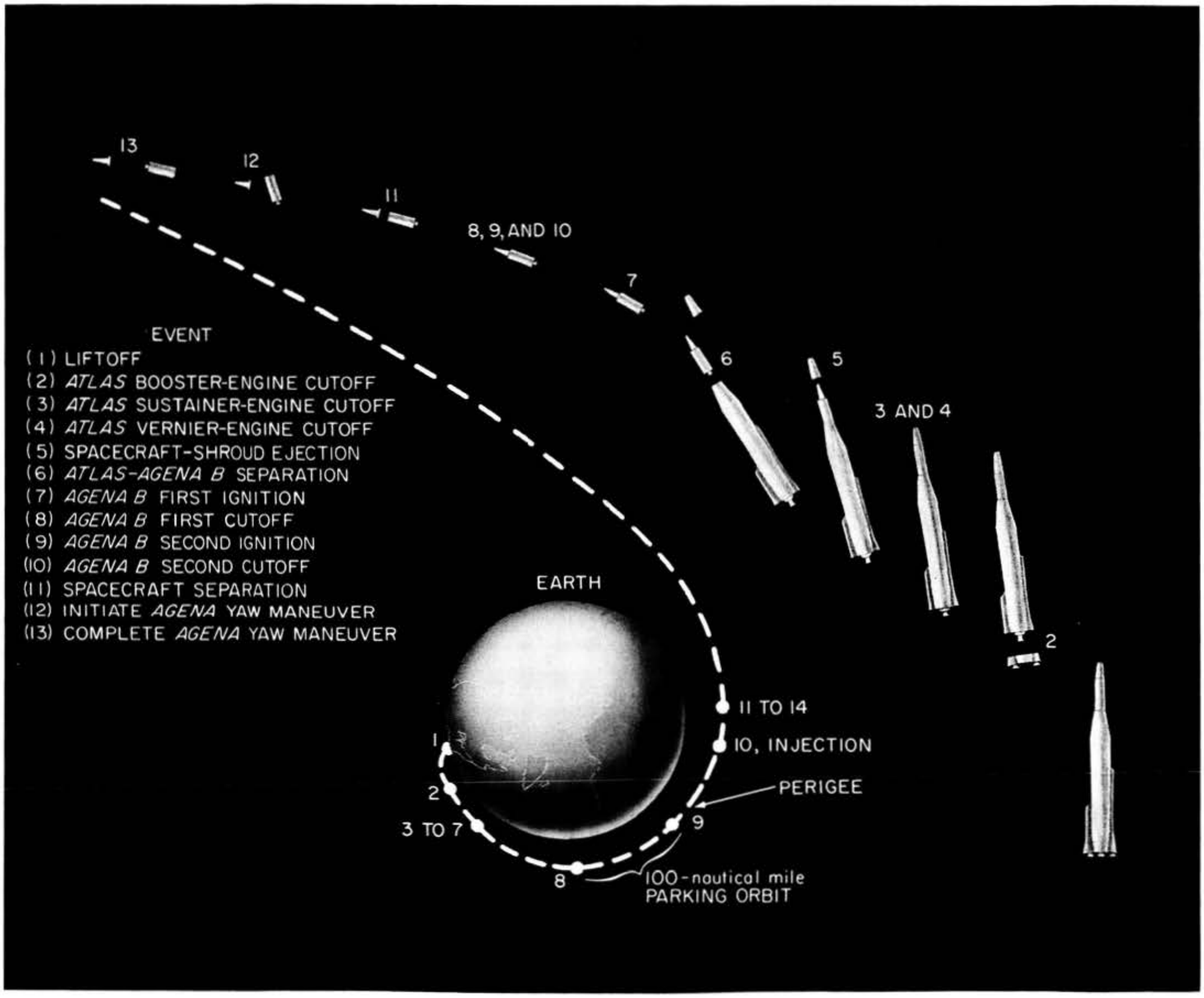


Figure 21. ***Ranger*** **launch-to-injection events**

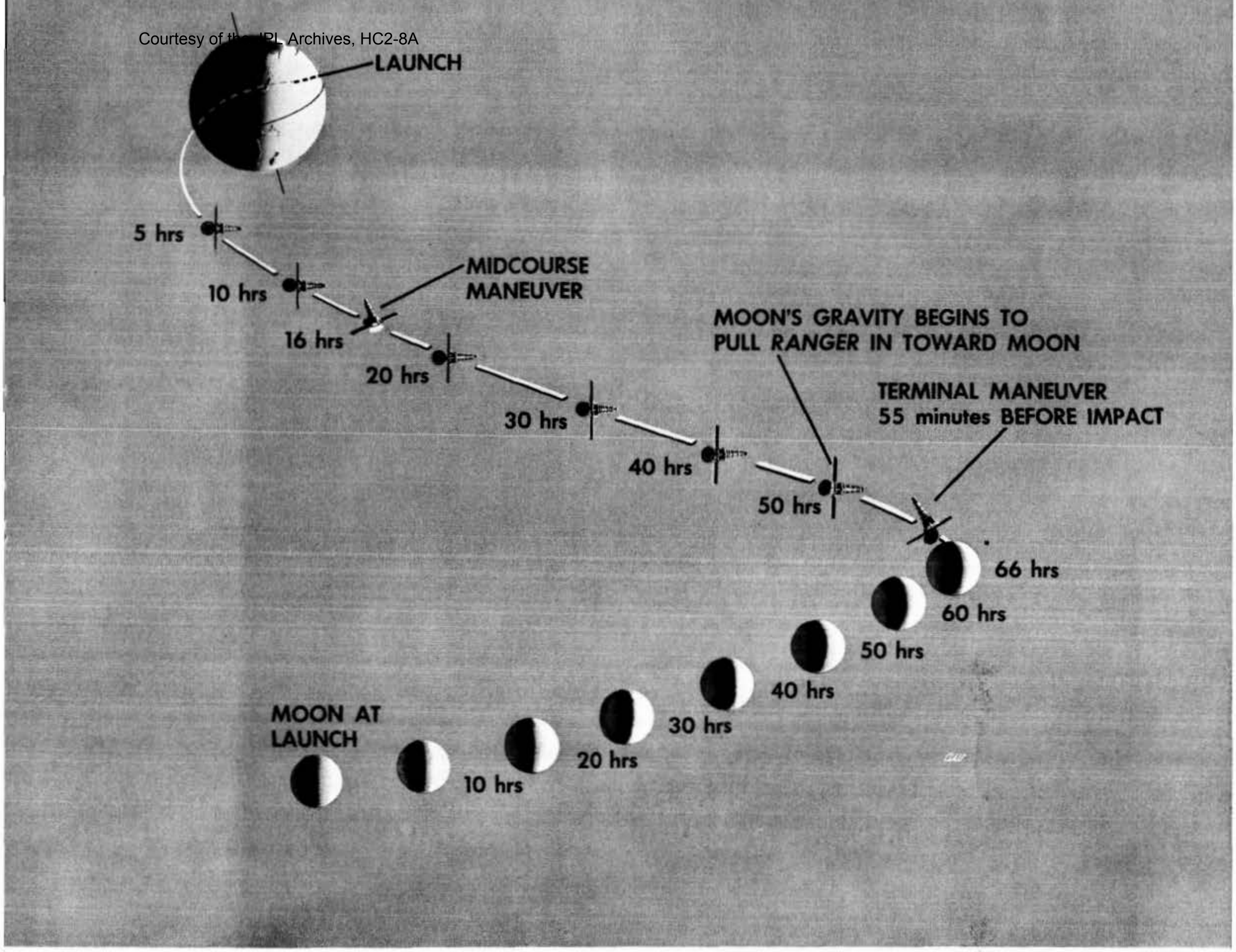


Figure 22. ***Ranger*** **trajectory to Moon**

of the spacecraft is accomplished by the attitude control system's combining of signals received from its Sun sensors and the autopilot's rate gyros.

At the same time that the CC&S orders Sun acquisition, it orders the high-gain directional antenna extended. A drive motor extends the antenna to a present hinge angle that was determined before launch.

In order to conserve gas, the attitude control system permits a pointing error of ½ degree on either side of the Sun making the total pointing error 1 degree. If the error becomes greater, the sensors signal the gas jets and they fire as necessary to again lock the spacecraft onto the Sun. It is calculated that on the average the gas jets fire for 1/60 of a second every 60 minutes to keep the spacecraft's solar panels pointed at the Sun.

The Sun acquisition process is expected to take about 30 minutes. As soon as the solar panels are locked on the Sun, the power system begins drawing electric power from the panels. After that time, the batteries only supply power in the event of a peak demand that the panels cannot handle and during the midcourse and terminal maneuvers.

Earth Acquisition

The next sequence of events commanded by the CC&S is the acquisition of Earth by the high-gain directional

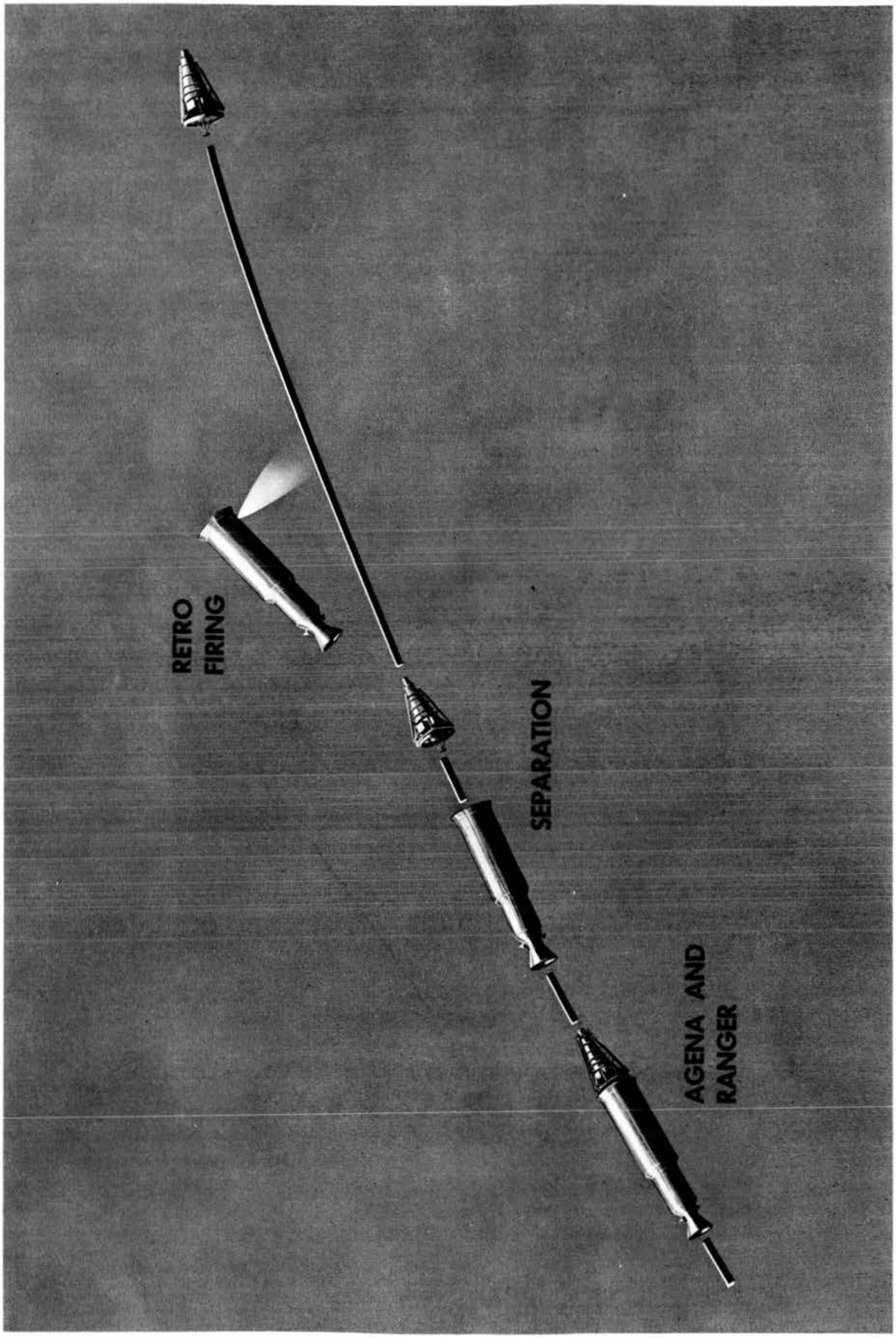


Figure 23. ***Agena–Ranger separation sequence***

antenna. This action is initiated at approximately 3½ hours after launch. A capability is provided to back up the initiation of this event by a radio command from Earth, if necessary. The attitude control system's Earth sensor is activated (its secondary Sun sensors turned off), and discharges from the gas jets roll the spacecraft.

The spacecraft maintains its lock on the Sun and, with its high-gain directional antenna pointed at a preset angle, rolls about its long axis and starts looking for the Earth. It does this by means of the three-section, photomultiplier tube operated Earth sensor mounted on, and aligned with, the high-gain antenna. During the roll, the Earth sensor sees the Earth and informs the attitude control system. Gas is discharged from the jets as required to keep the Earth in view of the sensor, and thus lock onto the Earth. Earth acquisition requires approximately ½ hour.

With the completion of Earth acquisition (Fig. 13), the spacecraft is 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. There is some danger that the Earth sensor, during its search for the Earth, may see and lock onto the Moon. But telemetry later will inform Earth stations if this has occurred, and Earth stations have the ability to send an override command to the attitude control system to tell it to look again for the Earth. If such action is not sufficient, the stations can send a hinge override command to change the hinge angle of the high-gain antenna and then order another roll search. When the Earth is acquired, the spacecraft's transmitter is switched from the omni-antenna to the high-gain antenna by a command from Earth.

A rise in signal strength on Earth will be an indication that acquisition of the high-gain antenna has been achieved. Confirmation will be afforded by analysis of telemetry to determine the angle of the antenna hinge.

With Sun and Earth acquisition achieved, *Ranger* is in its cruise mode.

Cruise and Midcourse Phase

Ranger continues in cruise mode until time for the midcourse trajectory correction maneuver (Fig. 24). After launch, most of the activity on the lunar mission is centered at the DSIF Stations and at the Space Flight Operations Center at JPL.

Tracking data collected by the stations are sent to JPL and fed into a large-scale computer system. The computer compares the actual trajectory of *Ranger* with the course required to yield a collision course with the Moon. If a correction is necessary to achieve the proper flight path, the computer provides the necessary figures to command the spacecraft to alter its trajectory. This involves determining the proper roll and pitch commands to point the spacecraft for the trajectory correction. Then the appropriately timed motor burn will provide the velocity required to change the direction and velocity of the flight.

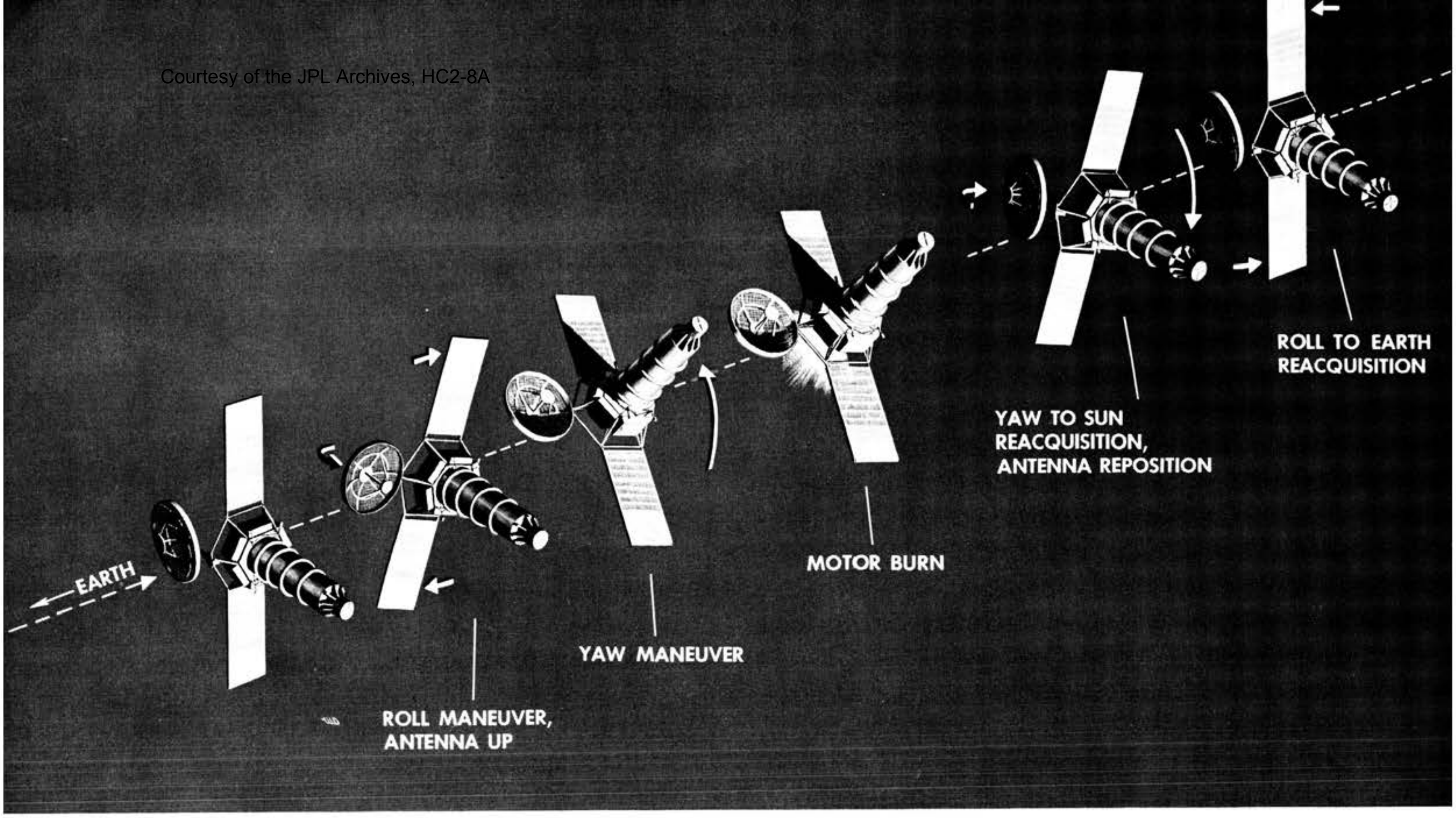
The order of events is precise. The first command from Goldstone to the spacecraft gives the direction and amount of roll required; the second gives the direction and amount of pitch needed; the third gives the velocity change determining the motor burn time. These data are stored in the spacecraft CC&S until Goldstone transmits a *go* command.

Prior to the *go* command, Goldstone will have ordered the *Ranger* transmitter to switch from the high-gain directional antenna to the omnidirectional antenna mounted at the peak of the superstructure.

Commands preprogrammed in the CC&S for the midcourse sequence initiate the following: The Earth sensor, mounted on the high-gain antenna, is turned off and the antenna itself moved out of the path of the midcourse motor's exhaust; the autopilot and accelerometer are powered; and pitch and roll turns are initiated. During the maneuver, the CC&S will inform the attitude control subsystem of the pitch and roll turns, as they occur, for reference against the orders from Earth. An accelerometer will provide acceleration rates to the CC&S during motor burn. Each pulse from the accelerometer represents a velocity increment of 0.03 meter per second.

The roll maneuver requires a maximum of 9½ minutes of time, including 2 minutes of settling time; the pitch maneuver requires a maximum of 17 minutes, including 2 minutes of settling time. When these are completed, the midcourse motor is fired and burns for the required time. Because the attitude control gas jets are not powerful enough to maintain the stability of the spacecraft during the propulsion phase of the midcourse maneuver, movable jet vanes extending into the exhaust control the attitude of the spacecraft in this period.

The jet vanes are controlled by an autopilot in the attitude control subsystem that functions only during the midcourse maneuver. The autopilot accepts information from the gyros to direct the thrust of the motor through the spacecraft's center of gravity in order to stabilize the craft.


EARTH
ROLL MANEUVER,
ANTENNA UP
YAW MANEUVER
MOTOR BURN
YAW TO SUN
REACQUISITION,
ANTENNA REPOSITION
ROLL TO EARTH
REACQUISITION

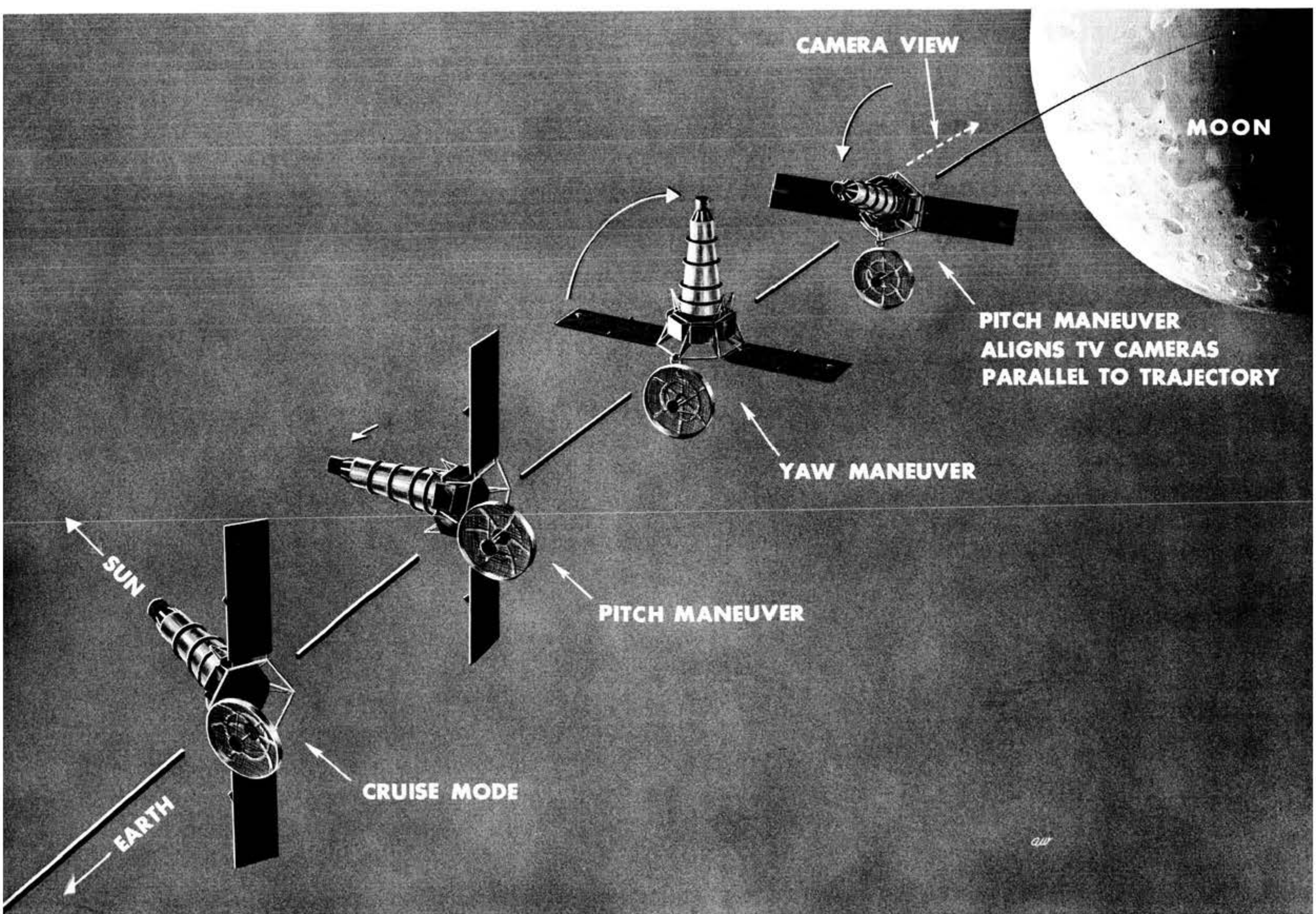

CAMERA VIEW
MOON
PITCH MANEUVER
ALIGNS TV CAMERAS
PARALLEL TO TRAJECTORY
YAW MANEUVER
SUN
PITCH MANEUVER
CRUISE MODE
EARTH

Figure 24. *Ranger* midcourse maneuver sequence

After the midcourse maneuver has placed the *Ranger* on the desired trajectory, the spacecraft again locks onto the Sun and Earth, transmissions are switched from the omni-antenna back to the high-gain directional antenna, and thus the spacecraft is again in the cruise mode.

Terminal Phase

Approximately 65 hours after launch (exact time depending on day and hour of launch) the Goldstone Station prepares to radio commands to the *Ranger* to instruct the spacecraft to perform the terminal maneuver (Fig. 25). This maneuver positions the spacecraft in the proper attitude, and thus aligns the six cameras with the descent path of the spacecraft as it drops to the Moon's surface.

JPL computers are determining the position of the spacecraft in its cruise mode in relation to the desired position for the terminal phase and are furnishing the angles and duration of the terminal commands. These are encoded, transmitted to the spacecraft, and stored in the CC&S. A radio command will have already been sent to prevent the television timer from causing early turn-on of the television system.

The first pitch command is followed by a command that yaws the spacecraft and then by a second pitch command. Completion of the terminal maneuver will require about 34 minutes. In the terminal mode, the spacecraft's solar panels are turned partly away from the Sun.

TV Sequence

At 1 hour before lunar impact, the DSIF Goldstone Tracking Station sends instructions to *Ranger* to begin the terminal maneuver. The terminal maneuver requires about 34 minutes to change the position so that the cameras are pointed in the direction the spacecraft is traveling. The spacecraft at this time is 4160 miles from the Moon and traveling at 3550 miles per hour.

At impact minus 15 minutes, the CC&S sends a command to turn on the television system for warm-up. A redundant command is provided by the Goldstone Station. At this point, the spacecraft is 2000 miles from the Moon; its velocity has accelerated to 4120 miles per hour because of the increasing effect of the lunar gravity.

Figure 25. *Ranger* terminal maneuver sequence

At impact minus 10 minutes, the camera sequencer sends a command to turn the cameras on full power. This command will be backed up by another from the CC&S.

From the time that the cameras start taking pictures until *Ranger* crashes on the Moon's surface, the two wide-angle cameras will take one picture every 2.56 seconds or about 117 pictures each. Because the spacecraft is falling at a velocity of 5190 miles per hour, a picture is taken every 4.4 miles. Each of the narrow-angle cameras takes 714 pictures during the descent phase, or one picture every 0.34 mile, at intervals of 0.2 second.

As indicated in Table 3, the first picture taken by the wide-angle camera equipped with the 1-inch lens shows a surface area of about 150,000 square miles. The last picture taken by the narrow-angle camera with the 3-inch lens will include an area of about 4200 square feet.

It is impossible to tell beforehand which camera will take the last picture. Because of this fact, plus the unknown lighting conditions, and the possibility that the angle of impact might not be vertical, the resolving power of the cameras can not be exactly predicted.

The pictures transmitted to Earth are received by two 85-foot-diameter parabolic antennas at the Goldstone Tracking Station (Figs. 26 and 27). These stations have special equipment to record the pictures on 35-millimeter film and also on magnetic tape.

Because the video data are transmitted by radio, a certain amount of noise will be present on the signals that form the pictures. This noise will be removed through superposition techniques; stereo evaluation will be performed wherever possible. The films will be analyzed by a staff of scientific investigators and experimenters.

Table 3. Lunar area covered by TV cameras

	Lunar altitude, miles	Cameras			
		Full view, square miles		Partial view, square miles	
		1-inch lens	3-inch lens	1-inch lens	3-inch lens
First pictures	875	151,000	16,800	9460	1050
Last pictures	4	3½	½	—	—
	⅓	—	—	1/700	1/7000

Figure 26. Echo Station

Figure 27. Pioneer Station