EARLY EXPLORATION OF THE MOON

Ranger to Apollo
Luna to Lunniy Korabl

TOM LUND

Springer

PRAXIS

Early Exploration of the Moon

Ranger to Apollo, Luna to Lunniy Korabl

More information about this series at http://www.springer.com/series/4097

Tom Lund

Early Exploration of the Moon

Ranger to Apollo, Luna to Lunniy Korabl

Springer

Published in association with
Praxis Publishing
Chichester, UK

PRAXIS

Tom Lund
San Diego, CA, USA

SPRINGER-PRAXIS BOOKS IN SPACE EXPLORATION

Springer Praxis Books
ISBN 978-3-030-02070-5 ISBN 978-3-030-02071-2 (eBook)
https://doi.org/10.1007/978-3-030-02071-2

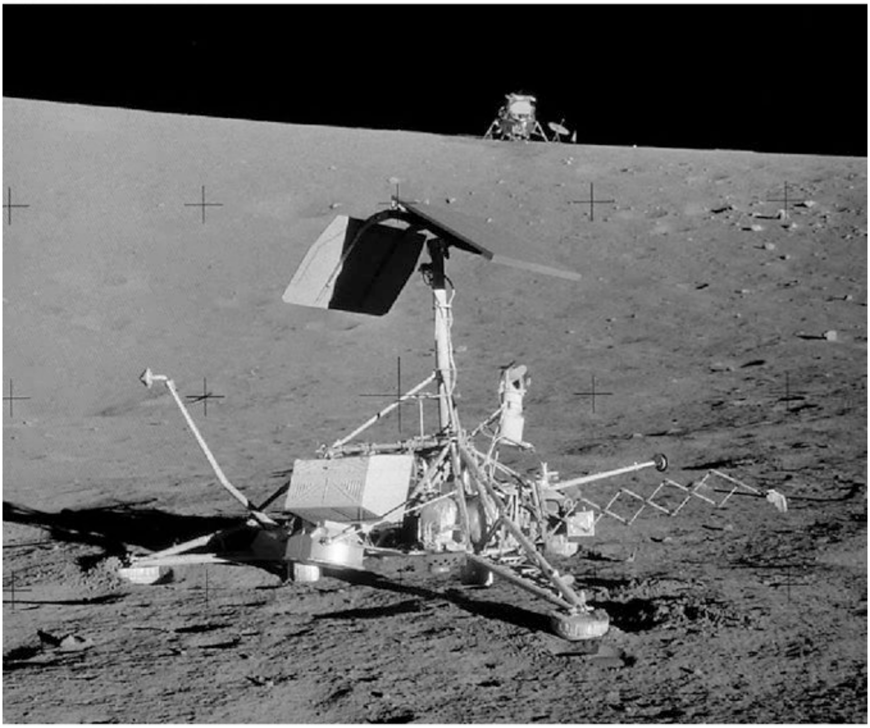
Library of Congress Control Number: 2018959133

© Springer Nature Switzerland AG 2018
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Cover design: Jim Wilkie. Image credit: NASA
Project Editor: David M. Harland

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Early Exploration of the Moon



Surveyor 3 and Lunar Module 6

Tom Lund

This book is dedicated
to my wife Barbara
and to my children
Ann, Tom, and Colin.

Contents

8 The Apollo Lunar Module

Introduction

The machines known as spacecraft that enabled early exploration of the moon were ingenious and reflected the best efforts of talented people working with the technology of the day. Those moon-bound spacecraft, designed in the 1960s, were remarkable for their performance, efficiency, and ruggedness. It is instructive to examine these machines and see just how capable they were and how best performance was wrung out of the technology available.

This book covers early lunar exploration efforts by the United States and by the Soviet Union. Russia was the major entity of the Soviet Union at the time, and the development of spacecraft was a Russian endeavor. Early exploration of the moon by the United States involved the Ranger, Lunar Orbiter, Surveyor, and Apollo spacecraft. The exploration advanced from taking photographs as the Ranger hurdled to impact the moon to the impressive manned lunar landing and exploration missions of Apollo. Russian spacecraft that explored the moon included lunar impactors, lunar flyby spacecraft, lunar landers, lunar orbiters, lunar sample return spacecraft, and the capable Lunokhod lunar rovers. The first five of those spacecraft were simply given the name Luna followed by a number. Russian hardware for a manned lunar landing did not rise to the task.

The author had significant responsibility for landing radars for both the Surveyor and Apollo programs. As a result, he had keen interest in all of the space programs during those pioneering years. Writing this book provided opportunity to relive some of those heady times and a chance to use material from his files.

The early space programs took place at a time when there were impressive aeronautical programs in the United States. The SR-71 Blackbird was cruising at Mach 3.2 at 80,000 feet with its crew of two for over 3,000 miles without breaking a sweat, and the X-15 was rocketing along at Mach 6.7 and reaching altitudes of 354,000 feet. The challenges of the difficult Apollo program did not seem insurmountable in that era.

The pinnacle of lunar exploration was the mission of Apollo 17 that saw the exploration of the moon by a trained geologist, Harrison Schmitt. Schmitt and Gene Cernan, commander of the mission, traveled 21 miles around the surface of the moon in a dune buggy-type vehicle, stopping frequently to explore. A striking photograph of Dr. Schmitt examining a large boulder on the surface of the moon is shown below (Fig. 1).

Fig. 1 Geologist Harrison Schmitt examining a boulder on the lunar surface (NASA photograph)

Early US hardware built for lunar exploration was dimensioned in English units. The author stuck with that treatment of units for US hardware in this book. An exception is the US Lunar Orbiter that used metric units, and that convention was retained. Russian hardware was dimensioned in metric units, and that convention was retained as well.

1

The Nature of the Moon

The moon is the most imposing feature of the night sky. Much is known about the moon today, thanks in part to exploration by the spacecraft discussed in this book. A few interesting facts about the moon are presented below to set the stage for the discussion of lunar exploration spacecraft that follows.

The moon is a satellite of the earth with an orbital period around the earth of 27.3 days with respect to the stars. The orbit is elliptical with an apogee of 405,504 km (252,022 miles) center-to-center from earth and a perigee of 363,396 km (225,852 miles). Perigee is the distance of closest approach, and apogee is the farthest distance from earth in the orbit. The plane of the moon's orbit around the earth is displaced 5.15 degrees from the ecliptic, or plane of the earth's orbit around the sun. The axis of rotation of the moon is displaced 6.68 degrees from perpendicular to the plane of the lunar orbit.

Interestingly, the rotation of the moon about its axis is locked to the earth such that the same face of the moon is always presented to the earth. This comes about because of a tidal bulge in the surface of the moon due to the gravity of the earth. This circumstance allows continuous communications from earth to spacecraft on the nearside of the moon. Deep space communications facilities at various locations around the earth allow this continuous communication.

The equatorial diameter of the moon is 3,476.2 km (2,160.5 miles) as compared to an equatorial diameter of 12,756.2 km (7,928.0 miles) for earth. The mean density of the moon is about 60% of that of earth, and the gravity at the surface of the moon is 1.62 m/s^2 (5.3 ft/s^2) compared with 9.80 m/s^2 (32.1 ft/s^2) at the surface of the earth. The factor of six reduction of gravity on the moon allowed the Apollo astronauts to easily move about on the lunar surface while carrying 139 pounds of life-support equipment on their back.

T. Lund, *Early Exploration of the Moon*, Springer Praxis Books,
https://doi.org/10.1007/978-3-030-02071-2_1

The orbital period of the moon around the earth of 27.3 days is known as the sidereal period. Since the earth, carrying the moon's orbit, is revolving around the sun, the moon must rotate more than 360 degrees for the sun to appear at the same elevation in the sky. Thus, it takes 29.5 earth days (708 hours) from sunrise-to-sunrise on the moon. The lunar day consists of 354 hours of light followed by 354 hours of darkness. The transition from light to darkness is abrupt since the moon has essentially no atmosphere.

The temperature of the lunar surface was measured in detail by an infrared radiometer on the US Lunar Reconnaissance Orbiter spacecraft. The surface temperature near the equator was measured at about 117°C (242° F) at lunar noon and about −179° C (−289° F) at the coldest time during the lunar night.

Composite photographs of the nearside and the far side of the moon are shown on the next two pages (Figs. 1.1 and 1.2). The composites were assembled from photographs taken by NASA's Lunar Reconnaissance Orbiter.

The nearside lunar surface contains low-lying maria as well as more rugged highlands. The maria, so-called because ancient astronomers equated the dark, smooth surface to seas (maria is plural for mare, the Latin name for sea), are relatively smooth and thought to be a result of lava flows. They are generally flat to gently rolling with numerous small craters. The highland regions are heavily cratered with many craters exceeding 20 km (12.5 miles) in diameter. The far side lunar surface is heavily cratered with only a few small patches of maria.

Like earth, the moon is composed of a crust, mantle, and core. The crust is the outer layer, and NASA data indicate that the thickness ranges from about 70 km (43 miles) to 150 km (93 miles). The core is made up of a solid, iron-rich center core about 240 km (149 miles) in radius, a molten layer 90 km (56 miles) thick, and a partially molten layer 150 km (93 miles) thick. The mantle extends from the top of the partially molten core layer to the bottom of the crust. It is made up of an upper rigid layer and a lower molten layer.

An important difference between the earth and moon is that the iron core accounts for only one to three percent of the mass of the moon, whereas the iron core of earth accounts for 32.5% of earth's mass.

The origin of the moon has been conjectured for centuries. Today, the most accepted theory is that a fledgling planet about the mass of mars impacted the earth with a glancing blow about 4.5 billion years ago. The moon formed from the remnants of the impacting body and debris from earth. This violent creation model is referred to as the impact theory. Other theories have been advanced, but most have been discarded for not agreeing with one or more known facts. One stubborn fact is that samples of rock returned from the moon by the Apollo missions have nearly identical chemical makeup as rocks on earth, even to identical ratios of the three isotopes of oxygen.

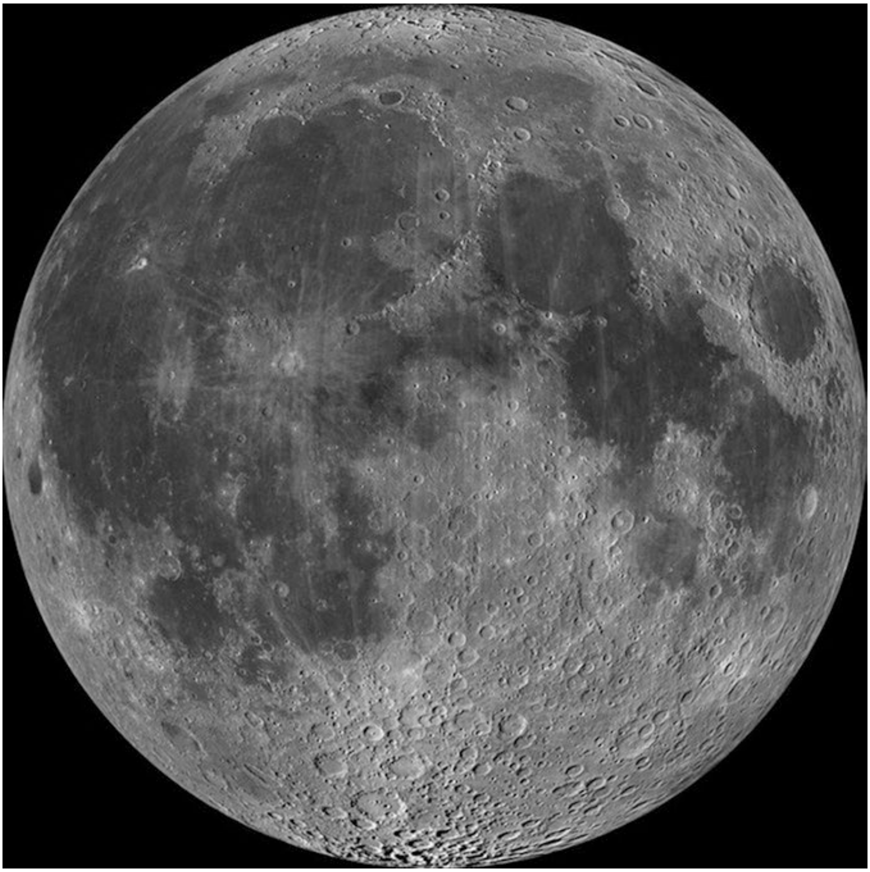


Fig. 1.1 Nearside of moon as imaged by Lunar Reconnaissance Orbiter (NASA photograph)

A formation theory that is presently receiving attention asserts that the collision between the earth and impactor was so violent that it vaporized the impactor and the upper mantle and crust of the earth. The vaporized material from the impactor and earth became homogeneous throughout its extent. The vapor condensed around the remnant of the earth's core to form a new earth, and the moon condensed around moonlets in the outer region.

The fascination about the origin of the moon continues with ongoing discussion and study.

So, what is the moon really made of? This age-old question was the objective of the capable and clever series of early spacecraft launched to the moon by the United States and the Soviet Union in the 1960s and early 1970s. At the end of this early exploration period, the world had a good idea of the composition of the moon.

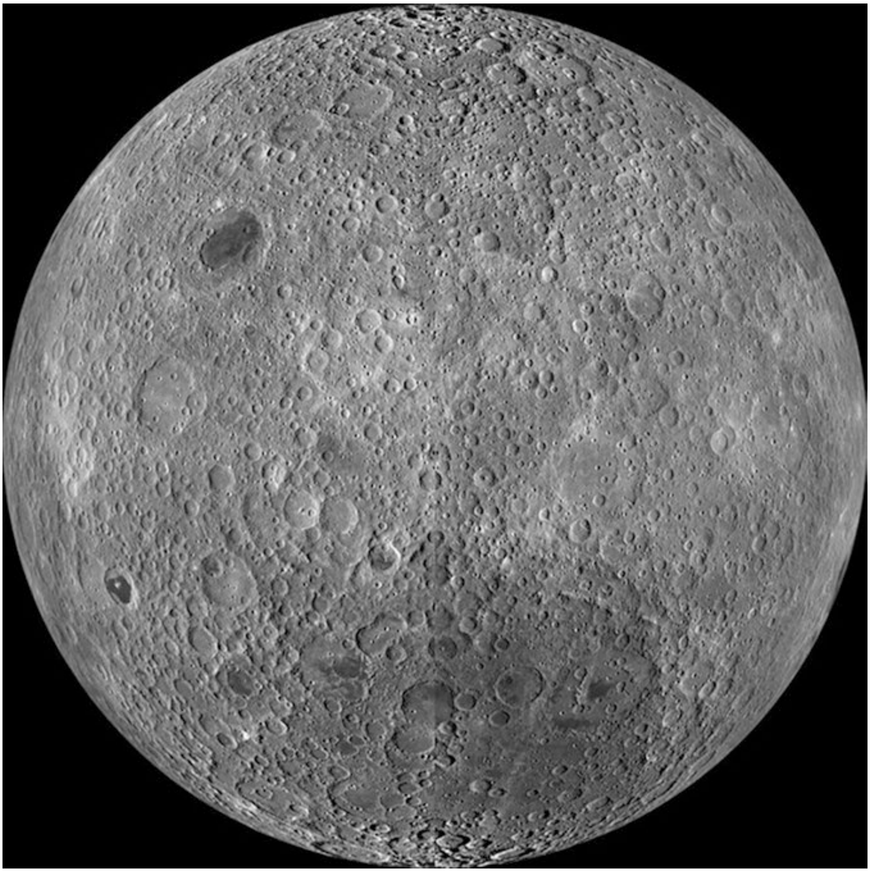


Fig. 1.2 Far side of moon as imaged by Lunar Reconnaissance Orbiter (NASA photograph)

In total, the six Apollo missions that landed on the moon brought back 842 pounds of lunar rocks and soil for analysis on earth. The Soviet Union conducted three successful unmanned landing and sample return missions that returned a total of about 0.8 pounds of material from three lunar sites.

Chemical analysis of the returned material from Apollo missions varies from site to site, but the average compositions of the lunar surface of the two most common elements by weight were oxygen at 43% and silicon at 20%. For comparison, on average the two most common elements in the earth's crust by weight are oxygen at 46.6% and silicon at 27.7%.

Hamish Lindsay, writing about the Apollo Lunar Surface Experiments Package, states that the early moon was covered by a deep magma ocean. The present lunar highlands formed from low-density rocks that floated to the surface. The main composition of those rocks is feldspar, a mineral rich in calcium and aluminum.

The cooling magma ocean was bombarded by massive asteroids whose impact left huge basins that filled with lava. These basins, now referred to as maria, are made up of basalt rocks that are rich in magnesium and iron.

The rock on the surface of the moon has been ground up by impacts of comets and asteroids over millions of years. Much of the debris, or regolith, on the surface is a very fine powder. There was a concern that a landing spacecraft might sink a considerable distance into the powder, but this proved not to be the case.

Bibliography

Boyle, Rebeca, *What Made the Moon? New Ideas Try to Rescue a Troubled Theory*, https://www.quantamagazine.org

Earth's Moon, NASA Science website

Lindsay, Hamish, *ALSEP Apollo Lunar Surface Experiments Package*, Apollo Lunar Surface Journal, 2008

Taylor, S. R., *The Origin of the Moon: Geochemical Considerations*, Proceedings of the Origin of the Moon Conference, October 1984

Williams, David R., *Moon Fact Sheet*, NASA Science website

2

The Ranger Lunar Photography Mission

The Ranger project was designed to send a spacecraft to the moon and take a series of photographs of the lunar surface as the spacecraft descended toward impact. The project was fraught with failures, but it was finally successful, and high-quality pictures were transmitted to earth.

A photograph of an engineering model of the successful Block III series of Ranger spacecraft is shown next page (Fig. 2.1).

EARLY US VENTURES INTO SPACE

A preceding program to gather information about the moon, Pioneer, had a troubled history as well, and it will be mentioned briefly here to give the reader a feel for some of the angst that accompanied early space exploration.

The Pioneer program, which was begun in March 1958, was managed by the newly formed Advanced Research Projects Agency (ARPA). ARPA was and still is an agency of the Department of Defense. Pioneer was intended to gather information about the moon, including pictures of the far side, during a flyby. It was a rather disjointed program consisting of three US Air Force launches of a spacecraft and two US Army launches of a different spacecraft. The Air Force used a Thor ballistic missile first stage and Vanguard liquid fueled second stage. The US Army used a Jupiter-C ballistic missile first stage and a solid fuel upper stage developed by the Jet Propulsion Laboratory (JPL). The spacecraft for the Air Force was developed by Space Technology Laboratories, and the spacecraft for the Army was developed by JPL.

The first launch of the Air Force Pioneer took place in August 1958. Pioneer 0, as it would later be called, ended shortly after launch in a spectacular explosion.

T. Lund, *Early Exploration of the Moon*, Springer Praxis Books,
https://doi.org/10.1007/978-3-030-02071-2_2

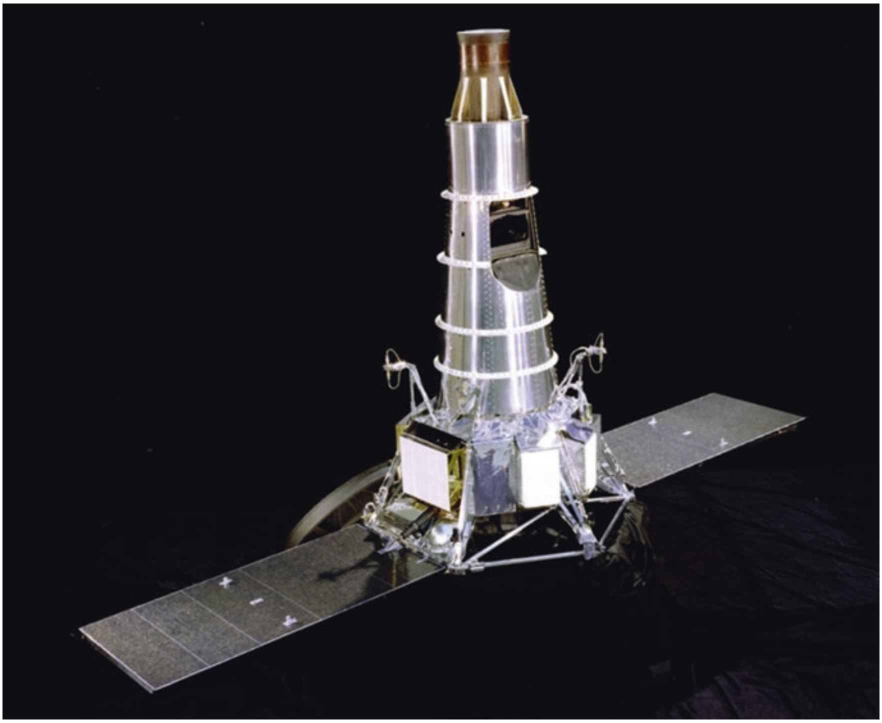


Fig. 2.1 Model of Block III Ranger spacecraft (NASA photograph)

The next two Air Force launches of Pioneer 1 and Pioneer 2 failed due to problems in the upper stage rocket.

The first launch of the Army system, Pioneer 3, failed due to premature cutoff of the first rocket stage. The second Army launch in March 1959 was a success, and Pioneer 4 became the first US spacecraft to escape earth's gravity. After four failures in a row, it was gratifying to have a success although the spacecraft passed about 37,000 miles from the lunar surface, about a factor of two more distant than intended. Pioneer 4 did not carry a camera because priority had been given to obtaining additional data on the radiation belts around the earth and radiation in the vicinity of the moon. Radiation measurements were successfully made.

The Ranger program that followed Pioneer had a turbulent beginning with controversy over the scope of the program and experiments to be carried by the spacecraft. It was the first lunar program to be conducted by the newly formed National Aeronautics and Space Administration (NASA).

NASA grew up with the early spacecraft covered in this book, and it is interesting to look at its early history.

EARLY HISTORY OF NASA

Several organizations were conducting space-related programs in the United States in the 1950s. The Naval Research Laboratory was launching the Vanguard satellite, the US Army and the US Air Force were developing intercontinental ballistic missiles (ICBMs), and ARPA was supporting a heavy-lift rocket program as well as developing a Lunar Orbiter. The National Advisory Committee for Aeronautics (NACA) was supporting research in all phases of aerodynamics and conducting flights of the X-15 manned rocket-powered manned aircraft that flew to the fringes of space. The X-15 reached altitudes of 354,000 feet (67 miles) and speeds of Mach 6.72 (4,517 miles per hour).

President Eisenhower favored consolidating all of the space programs into one civilian-controlled organization. This would include the Army and Air Force space activities that were not directly tied to military applications. Congress took up the challenge to bring about the National Aeronautics and Space Administration (NASA). Lyndon Johnson, Senate Majority Leader, and John McCormack, House Majority Leader, shepherded the bill establishing NASA through congress. Johnson and McCormack were democrats, but they embodied bipartisan support for national programs that is rare today. Republican President Eisenhower signed the bill establishing NASA into law on 29 July 1958.

Formulating NASA was also looked on as a way to respond to the burgeoning space program of the Soviet Union. Soviet space programs became big news upon their orbiting of the Sputnik satellite in October 1957. The Soviet program extended to the moon with the Luna 1, Luna 2, and Luna 3 spacecraft that were all launched in 1959.

The new NASA organization incorporated the venerable National Advisory Committee for Aeronautics (NACA), Langley Aeronautical Laboratories, Ames Aeronautical Laboratory, Lewis Flight Propulsion Laboratory, the Army Ballistic Missile Agency in Huntsville, and the Jet Propulsion Laboratory. The personnel and programs of NACA became the nucleus of the new NASA organization.

The newly incorporated organizations were directed from NASA Headquarters in Washington, DC. The first top executives for NASA Headquarters were Dr. Keith Glennan, NASA Administrator, and Dr. Hugh Dryden, Deputy Administrator.

The first location of NASA Headquarters was in the Dolley Madison House on Lafayette Square in Washington, DC. Headquarters occupied that historic house from 1958 to 1961. The ballroom of the house was used to introduce the first astronauts to the press in April 1959. NASA Headquarters later moved to larger quarters in Federal Office Buildings FOB-6 and FOB-10B. It is now housed in a new large building on E Street, just south of the National Mall. The building is shown below (Fig. 2.2).

Fig. 2.2 NASA Headquarters in Washington, DC, (NASA photograph)

Directors of the early field centers were:

Center	First director
Marshall Space Flight Center	Wernher von Braun
Langley Research Center	Henry Reed
Ames Research Center	Smith DeFrance
Goddard Space Flight Center	Harry Goett
Flight Research Center	Paul Bikle
Lewis Research Center	Edward Sharp
Jet Propulsion Laboratory	William Pickering
Launch Operations Center	Kurt Debus

OVERVIEW OF THE RANGER PROJECT

The original goal of the Ranger project was to gather information about the moon by several scientific instruments on the spacecraft and to obtain close-up pictures of the lunar surface. A series of pictures would be taken and transmitted to earth as the spacecraft descended toward impact on the moon. After failure of the first five Ranger missions, the direction of the program was changed, and effort was concentrated on obtaining high-quality close-up pictures of the lunar surface to support the upcoming Apollo program. The scientific instruments, some of which were quite complex, were removed from the spacecraft.

The Ranger program had its beginning in December 1959 when NASA Headquarters assigned the Jet Propulsion Laboratory (JPL) seven flights to reconnoiter the moon. The flights were planned to occur during 1961 and 1962. JPL would develop and build the various Ranger spacecraft as well as manage the project. Design concepts for the Ranger spacecraft were released by JPL in February 1960.

Top management personnel on the initial Ranger program at NASA Headquarters were Abe Silverstein, Space Flight Programs Director, and Ed Cortright, Lunar and Planetary Programs Chief. Oran Nicks, Chief of Lunar Flight Systems, was the hands-on manager for Ranger for the Space Flight Program Office.

Key management personnel initially for the Ranger program at JPL were Clifford Cummings, Lunar Program Director; James Burke, Ranger Project Manager; and Gordon Kautz, Ranger Project Assistant Manager. From accounts related in NASA Report SP-4210, all were capable and energetic persons.

Management relationships between NASA Headquarters and JPL were contentious as Headquarters tried to impose their will on the independent-minded Jet Propulsion Laboratory. JPL particularly resented technical direction. By the time of the successful Block III Ranger phase, three years into the program, management personnel had changed at JPL and at NASA Headquarters, and management issues were less contentious. Author Cargill Hall in *Lunar Impact: A History of Project Ranger* discusses the management discourse at some length.

The spacecraft in the project were organized into blocks that corresponded to phases of the project. Block I was a proving phase for the spacecraft and launch vehicles and integration of the two. Operation was to be confined to earth orbit.

Two flights were planned for Block I. The two spacecraft, Ranger 1 and Ranger 2, carried ten scientific instruments along with solar panels and vehicle stabilization equipment. The spacecraft would conduct scientific measurements as the spacecraft traveled in a highly elliptical orbit around the earth with perigee of 37,500 miles and apogee of 685,000 miles. The orbit would take the spacecraft behind the moon and return to the vicinity of earth. Each mission was expected to last about 5 months.

Block II would consist of three spacecraft, and they would travel to the moon and take photographs as the spacecraft descended toward impact. The Block II spacecraft would carry fewer scientific instruments than Block I, but it would carry a camera and a small lander. The lander would be detached from the main spacecraft and employ a retrorocket to slow it for a survivable landing. The scientific instrument of the lander was mounted inside of a crushable balsa wood sphere to enhance survival. The only instrument inside the lander would be a seismometer to measure lunar quakes. It would also contain a small transmitter to send seismic measurements back to earth.

Block III would consist of four spacecraft, Ranger 6, 7, 8, and 9. The spacecraft configuration would depend on the results of flights of Block I and Block II spacecraft.

The first of the two Block I spacecraft, Ranger 1, was launched in August 1961. The planned parking orbit around the earth was achieved, but the Agena-B upper stage only fired briefly leaving the spacecraft in a low earth orbit. The spacecraft itself performed all of its functions, but the orbit soon decayed, and the spacecraft burned up reentering the atmosphere. Ranger 2 was launched in November 1961, but again the Agena-B upper stage failed, and the spacecraft soon burned up reentering the earth's atmosphere.

The first of the Block II spacecraft, Ranger 3, was launched in January 1962. It failed to achieve the desired trajectory and missed the moon by 22,860 miles (36,785 km). Ranger 4 was launched in April 1962, and its trajectory was good toward the moon, but an electronic failure left the spacecraft unresponsive to commands from earth. Ranger 5 was launched in October 1962, but a short circuit in the solar panel circuits left only battery power and that soon ran out leaving the spacecraft dead.

Five failures in a row could not go unanswered. Investigation boards were set up, all aspects of the project were probed, and there was call for an overhaul of the Ranger program with greater emphasis on reliability and quality control. Additional redundancy of critical functions was also incorporated. In keeping with common practice of firing the coach of a losing sports team, the JPL Lunar Program Director, Clifford Cummings, and Ranger Project Manager, James Burke, were replaced. Robert Parks became JPL Lunar and Planetary Program Director, and Harris Schurmcier became Ranger Project Manager.

The direction of the Ranger project was changed for the Block III missions to give priority to photographing the lunar surface in support of the upcoming Apollo program. The scientific instruments and lander that were present on the Block II spacecraft were eliminated, and a set of cameras were installed instead. Block III included four spacecraft: Rangers 6, 7, 8, and 9. Those spacecraft carried a very capable set of six cameras to image the lunar surface as the spacecraft descended toward impact.

A photograph of a model of the Block III Ranger spacecraft was shown on the second page of this chapter. A viewing port for the cameras was located in a cutout located part way up on the conical vertical structure shown in the photograph. The top edge of a large steerable parabolic antenna can just be seen in the photograph behind the body of the spacecraft.

The six cameras carried by Block III spacecraft had different fields of view and resolution. The last picture would be taken less than a second before impact at altitudes of a few thousand feet. The pictures were transmitted to earth in near real time.

Ranger 6 was launched in January 1964. The launch vehicle was a US Air Force Atlas missile with an Agena-B upper stage. Initially, all aspect of the flight looked good, and the spacecraft impacted the moon within 19 miles of the aim point. However, when the cameras were turned on, only noise was received. The problem was traced to the cameras being inadvertently turned on for about a minute shortly after launch while still in the earth's upper atmosphere, and their high-voltage power supplies arced and burned out.

Ranger 7 was launched in July 1964 and the mission was a complete success. A total of 4,308 good-quality photographs were transmitted to earth as the spacecraft descended over the Mare Nubium (Sea of Clouds) region. The first photograph of the lunar surface was taken when the spacecraft was 1,311 miles above the surface. Photographs continued to be taken down to an altitude of about 1,440 feet. The last picture taken had a resolution of about 1.6 feet.

Ranger 8, launched in February 1965, was also a complete success. It returned 7,137 good-quality photographs of the Sea of Tranquility region.

Ranger 9, also a success, was launched in March 1965. It returned 5,814 good-quality photographs of the Alphonsus crater region.

Promising looking landing sites for the Apollo spacecraft that were apparent in the photographs taken by Ranger 8 influenced selecting the Sea of Tranquility landing site for the Surveyor 5 and Apollo 11 spacecraft. Indeed, the Apollo 11 astronauts established Tranquility Base just 44 miles from the impact site of Ranger 8.

The total cost of the Ranger project, including development, launch, and support, was $170 million.

LAUNCH OF RANGER SPACECRAFT AND FLIGHT TO THE MOON

The Ranger spacecraft was launched toward the moon from Cape Kennedy, Florida, by Atlas LV-3/Agena-B launch vehicles. The spacecraft, with solar panels folded up and parabolic antenna folded under the spacecraft, was fit into the nose cone attached to the Agena-B upper stage. A photograph of the launch of Ranger 8 in February 1965 is shown on the next page (Fig. 2.3).

The Agena-B stage is the upper portion of the vehicle in the photograph. It extended down to the nose fairing of the Atlas first stage. The Agena-B engine nozzle extended down past the black cylindrical area in the photograph to inside the Atlas nose fairing. The overall launch vehicle was about 100 feet tall.

Fig. 2.3 Launch of Ranger 8 in February 1965 (NASA photograph)

The Atlas was 10 feet in diameter, and the Agena-B was 5 feet in diameter. The weight of the overall vehicle including the Block III Ranger spacecraft was about 276,800 pounds at liftoff.

The Atlas LV-3 first stage was built by General Dynamics. Five engines powered the Atlas at launch: two booster engines, one sustainer engine, and two vernier engines. The engines all burned rocket propellant-1 (RP-1), which was highly refined kerosene. The oxidizer was liquid oxygen.

The two booster engines generated 150,000 pounds of thrust each, the sustainer engine generated 57,000 pounds of thrust, and the two vernier engines provided 1,000 pounds of thrust each. All of these thrust levels were at sea level. The thrust was higher in a vacuum. The total thrust at liftoff was about 359,000 pounds, well above the 276,800 pound weight of the overall vehicle.

The booster engines were mounted on gimbals that allowed each engine to pivot 5 degrees in pitch and 5 degrees in yaw with respect to the centerline of the Atlas. The pivoted booster engines were used to steer the vehicle to a preprogrammed trajectory after launch. The trajectory followed an arc that gradually tilted from vertical at launch toward the horizontal as the vehicle gained altitude and speed.

The powerful booster engines were shut off and jettisoned along with their associated fuel pumps about 145 seconds after liftoff. The vehicle was about 36.4 miles above the earth at that time. The sustainer and vernier engines of the Atlas continued to burn until they were cutoff about 92 miles above the earth and near orbital velocity.

The sustainer engine was also gimballed, and it could be pivoted 3 degrees in pitch and 3 degrees in yaw about the centerline. It thrusted along the centerline while the boosters were firing. Its pivoting ability was used for steering after the booster engines burned out and were jettisoned. The vernier engines of Atlas could be positioned within a 140 degree arc in pitch and 50 degree arc in yaw. This positioning capability allowed the launch vehicle to be rolled to the desired orientation and to be controlled in pitch and yaw.

The total amount of propellant (fuel and oxidizer) carried by the Atlas was about 114.8 tons. Of this, about 74.6 tons was used during the booster firing, and the remainder, 40.2 tons, was available for use by the sustainer and vernier engines.

The Agena-B upper stage was built by the Lockheed Missiles and Space Company. It contained one engine that burned unsymmetrical dimethyl hydrazine as fuel and fuming nitric acid as oxidizer. This combination was hypergolic, igniting upon contact with one another. The engine was developed and built by Bell Aerosystems as their Bell model 8091. The engine generated 16,000 pounds of thrust in a vacuum, and it could be shut down and restarted twice in orbit. Agena-B carried about 6.1 tons of fuel and oxidizer, and that gave a total burn time of 240 seconds. The Agena was 5 feet in diameter in the propellant and equipment areas and 23.7 feet long.

The launch and subsequent thrusting and maneuvering to guide Ranger 8 toward impact at a targeted spot on the moon are described below.

Ranger 8 was launched from Cape Canaveral, Florida, on 20 February 1965. All three engines of the Atlas burned normally. The booster engine cutoff (BECO) command was given at the proper time, and the booster engines were jettisoned. Steering commands for the sustainer engine were generated by the large digital computer at the Cape and sent by radio link to the Atlas. The computer also determined the proper time to cut off the sustainer engine, and this was transmitted to Atlas at the appropriate time.

The Agena-B upper stage with Ranger attached was established in a parking orbit around the earth at an altitude of 115 miles and 7 minutes after launch. The spacecraft velocity at this time was about 17,500 miles per hour. At 21 minutes after launch, the Agena-B was ignited for a 90 second burn that put Agena/Ranger into an injection trajectory to impact the moon. The spacecraft velocity was about 24,475 miles per hour after the burn.

Ranger was then separated from Agena. The solar panels were deployed, and the spacecraft was oriented in space with the longitudinal axis pointed at the sun. The orientation was performed by gas jets controlled by the stabilization system from inputs from the sun sensors. The high-gain antenna was then deployed, and the spacecraft was rolled about the longitudinal axis until the earth sensor sensed the earth and provided signals to stop the roll and lock to the direction of earth. The antenna was then rotated on its hinge to align with the earth.

A midcourse correction was made when the spacecraft was about 99,440 miles from earth to bring the impact site on the moon close to the target. The spacecraft was first oriented to an altitude where the burn of Ranger's rocket engine would produce the desired correction. A 59 second burn of the rocket was then made to perform the correction. The rocket motor generated a thrust of 50 pounds.

Parameters of the midcourse correction had been calculated very well, and the correction resulted in the spacecraft impacting the moon within 14 miles of the initial aim point in the Sea of Tranquility. The accuracy was commendable given that the moon was over 224,000 miles away from earth at the time of launch.

Deep Space Tracking Network

Key to guiding the spacecraft close to the targeted impact point on the moon was trajectory measurements from the Deep Space Network. Operators at mission control were able to determine the trajectory of the spacecraft very accurately by using inputs from that network and send up instructions for midcourse corrections to refine the trajectory.

The Deep Space Network, at the time of flight of the Ranger spacecraft, was made up of stations at Goldstone Dry Lake in California, Island Lagoon (a dry lake bed) in Australia, and in a valley near Johannesburg, South Africa. The three stations allowed continuous tracking and communicating with the spacecraft from the rotating earth. Each station had a large parabolic antenna 85 feet (26 meters) in diameter that could be steered very accurately in azimuth and elevation to track the spacecraft. Once the spacecraft was in space, radio signals received from the spacecraft were used to automatically position the antenna to track the spacecraft.

Uplink commands were sent to the spacecraft by a 10 kilowatt, 890 MHz transmitter that fed the big antenna. The Ranger spacecraft had a transponder that phase locked to the uplink signal, modulated it with telemetry data, and translated it to 960 MHz for transmission back to earth. The phase-lock process allowed the two-way Doppler shift of the communication link to be measured very accurately, and this in turn gave very accurate measurement of relative velocity between the spacecraft and the earth-based antenna. The combination of very accurate velocity measurement and antenna angle measurement allowed accurate determination of the spacecraft trajectory.

CONFIGURATION OF RANGER SPACECRAFT

The spacecraft built for Block I, Block II, and Block III phases of the Ranger program were substantially different. The Block III spacecraft were successful in sending back high-quality photographs of the lunar surface. The Block I and Block II spacecraft all failed in their missions for various reasons. Details of those spacecraft will not be covered in this book.

Block III Ranger

Two views of the Block III Ranger spacecraft are shown in the drawings below and on the next page. The Block III spacecraft was less complicated than either the Block I or Block II spacecraft. The only scientific payload carried was a very capable set of six cameras.

The basic frame of the spacecraft was a hexagonal structure 5 feet across. A truncated conical structure clad with polished aluminum was attached to the top of the frame of the spacecraft. The conical tower was 27 inches at its base and 16 inches at the top. A cylindrical omnidirectional antenna was mounted at the top of the tower. The cameras were mounted within the tower, and a cutout in the side of the tower provided a viewing port (Figs. 2.4 and 2.5).

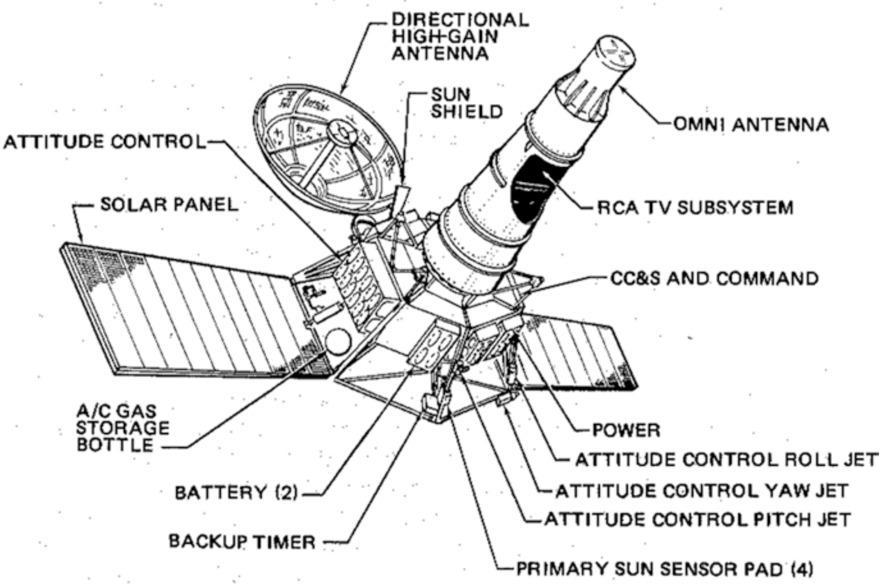


Fig. 2.4 View of the Ranger III spacecraft from the top (NASA graphic)

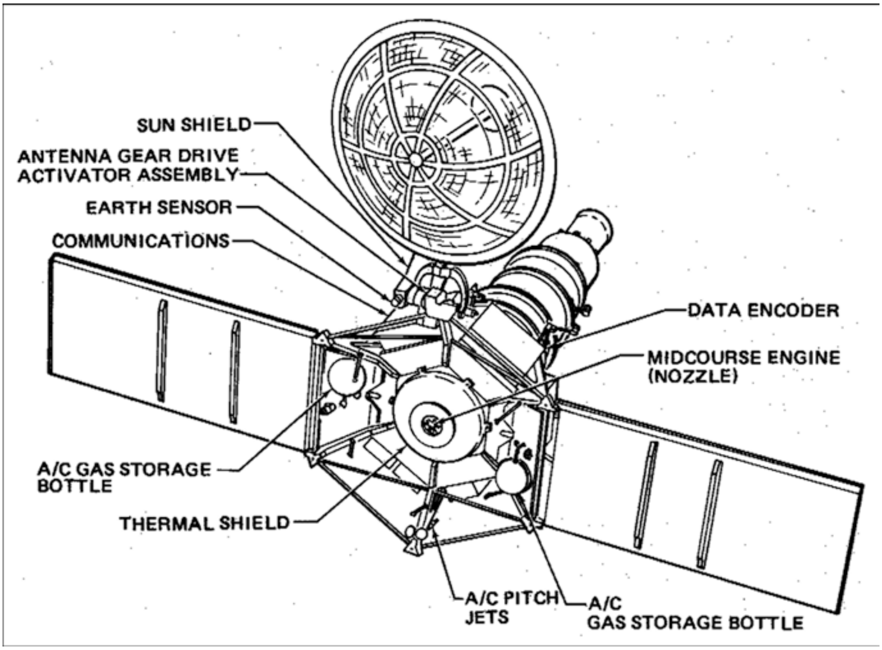


Fig. 2.5 View of the Ranger III spacecraft from the bottom (NASA graphic)

The cameras are labeled as RCA TV SUBSYSTEM in the top view of the spacecraft. The spacecraft contained two independent camera channels, the F-channel and the P-channel. Each channel had a separate battery, power supply, camera control electronics, and transmitter. The two batteries, two power supplies, and two sets of camera electronics were mounted inside the tower.

The hinged solar arrays were rectangular and 28.9 inches wide and 60.5 inches long. The total span across the two arrays was 15 feet. The total height of the spacecraft was 11.8 feet. The solar arrays generated about 200 watts of power for the spacecraft. Two batteries, each with a 1,000 watt-hour capacity, were available for backup power before the solar arrays were deployed. Each of the camera channels had a 1,200 watt-hour battery that was capable of powering the cameras, camera control electronics, and the 60 watt transmitter for 9 hours.

Cameras for Block III Rangers

The main purpose of the Block III Ranger spacecraft was to take photographs of the lunar surface to ascertain if it would be feasible to land the manned Apollo spacecraft on that terrain. To that end, a capable set of six cameras were mounted in the spacecraft. A photograph of the lenses of six cameras is shown on the next page (Fig. 2.6).