COMMENT EDITION

LUNAR ORBITER: A PRELIMINARY HISTORY

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by

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August 1969

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PREFACE

Three summers ago I came to NASA Headquarters as a member of the Summer Historical Seminar directed by Dr. Eugene M. Emme, the NASA Historian. I chose to research and write a paper on the Lunar Orbiter Program. My first period of research on Lunar Orbiter led me to conclude that a history of this program so vital to the Apollo mission would require more than the preliminary paper which I prepared in July and August 1967.

My research in 1967 led me to visit the Langley Research Center where I conducted interviews with members of the Lunar Orbiter Project Office during a one week stay in July. In August 1967, I went to the Kennedy Space Center to attend the launch of the fifth and final Lunar Orbiter spacecraft. At this time I interviewed more personnel connected with the management of the program. Returning to Washington I pursued my series of interviews by talking to officials of the Office of Space Science and Applications.

I returned to the NASA Historical Division in the summer of 1968 to deepen my research and to begin writing a program history of Lunar Orbiter and rewriting major portions of the original 1967 manuscript. Returning to my graduate studies in Russian history at the University of Maryland, in September 1968, I later spent part of the Christmas vacation, semester break and Easter vacation working on the revised manuscript.

In June 1969 I again returned to work at NASA Headquarters, this time under Lee R. Scherer, the former Lunar Orbiter Program Manager, who now directs the Apollo Lunar Exploration Office. Working
in an environment directly involved with the continued exploration of the Moon greatly animated my research and writing, and I completed the present manuscript in August 1969. More extensive document sources became available than I had used in the past, and the last four chapters of the history were rewritten to reflect this new information. Dennis B. James of Bellcomm, Inc. was instrumental in opening my eyes to several glaring deficiencies in my descriptions of the mission planning phase of the Lunar Orbiter Program.

I have benefited greatly from the support and encouragement of Dr. Eugene M. Emme, Dr. Frank W. Anderson, Jr., and the NASA Historical staff, and of Lee R. Scherer, Leon J. Kosofsky, Robert P. Bryson, William Shirey, and other members of the Apollo Lunar Exploration Office staff. Mrs. Grace Reeder, the NASA Headquarters Librarian, has supported me by obtaining valuable documents and publications pertaining to Lunar Orbiter, and I extend my thanks for her invaluable cooperation. Moreover, my appreciation and thanks go to Clifford H. Nelson and the staff of the Lunar Orbiter Project Office at Langley, most members of which subsequently formed the Viking Project Office for the Mars-Orbiter of the early seventies. It was they who first introduced me to the aspects of the program. R. Cargill Hall, JPL Historian, also was very helpful on some critical points.

Finally, this manuscript would still be handwritten had not Rosemary Ferguson and Barbara Wood taken upon themselves the arduous task of typing, correcting, and retyping the final draft from my scribblings.

This preliminary history reflects definite biases. It presents
the role of Headquarters officials more completely than it does those of Langley officials and other NASA activities. It lacks any analysis of Boeing management and the problems peculiar to the operation of the prime contractor except as they may have been revealed in NASA document sources. I have not examined in detail the contributions to program operations made by the Jet Propulsion Laboratory. Moreover, I have attempted to write a survey of the Lunar Orbiter Program rather than developing fully certain of its critical phases. An extensive bibliography is offered as compensation for my biases so that the reader might evaluate my work and perhaps explore certain phases of the program in greater detail than I have. This work constitutes a history and is not a management or policy study. Critical comments will be gratefully received. The reader should regard this as a history, chronological in organization, and should keep in mind that it attempts to make but one contribution to the growing record of space exploration.

Bruce K. Byers
August 26, 1969
# LUNAR ORBITER: A PRELIMINARY HISTORY

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INTRODUCTION

If one considers the elapsed time span since the United States first began developing systems for extraterrestrial observations and exploration of the Moon, ten years have passed. During this decade the people of America have succeeded in fulfilling one of man's oldest dreams -- to escape the Earth, set foot upon the Moon, and return. Many authors down through the centuries have written about the Earth's natural satellite, but relatively little was known about the Moon until in the decade of the sixties men committed themselves to landing there and returning to Earth.

This commitment and the further exploration of space will alter men's conceptions about themselves, their world, the Moon, and their place in the solar system. This will lead to totally new concepts as man makes discoveries and uncovers still unknown mysteries about the vast environment of which the Earth, the Moon, and the solar system form but an infinitesimal part. The history of this exploration will have many chapters because it is a part of the continuing history of mankind's struggle to know and live in an ever-changing environment. The preliminary chapters about America's first decade in space are already being written. As part of this the history of America's efforts to explore the Moon by various means describes the dominant arena of activity during the last ten years.

As part of this the National Aeronautics and Space Administration's
Lunar Orbiter Program successfully contributed to the activities which made the Apollo manned lunar landing in July 1969 a pioneering achievement in the name of all mankind. The author of *Lunar Orbiter: A Preliminary History* tells of one of NASA's significant lunar exploration programs which helped to make the Apollo landing possible. The history also suggests how the experience and techniques gained through the Lunar Orbiter Program might apply to future planetary missions. The accomplishments of Lunar Orbiter in fulfilling Apollo requirements present the major subject of this history. However, the extent to which its photographic data of the Moon will prove significantly useful to further studies of that planet has yet to be determined. Thus this first history of the program is preliminary. Hopefully it will contribute to a better understanding of America's space program and of the preparations involved in man's first journey to the Moon.

Lee R. Scherer, Lunar Orbiter Program Manager
August 1969
CHAPTER I

UNMANNED LUNAR EXPLORATION AND THE NEED FOR A LUNAR ORBITER

Three major undertakings of the National Aeronautics and Space Administration have thrust America's unmanned exploration of the Moon outside of the Earth's atmosphere: the Ranger Program, the Surveyor Program, and the Lunar Orbiter Program. Initiated before President John F. Kennedy's May 25, 1961, request for a national decision to make a manned lunar landing during the decade of the sixties, Ranger and Surveyor gave the United States its first close look at the Moon. The original objectives of the Ranger and Surveyor Programs had not envisioned imminent exploration of the Moon by men. Instead NASA had developed highly proficient instrumented means for preliminary exploration without direct applications in an undertaking such as the Apollo Manned Lunar Landing Program.

Unlike Ranger and Surveyor, the Lunar Orbiter Program began in 1963, after the creation of the Apollo Program. NASA's Office of Space Science and Applications (OSSA),¹ director of the Ranger and Surveyor Programs at the Jet Propulsion Laboratory (JPL), Pasadena, California, initiated Lunar Orbiter with Apollo requirements for photographic data of the Moon's surface as its primary mission. NASA Headquarters assigned the program to the Langley Research Center. Lunar Orbiters eventually obtained photographs of potential Apollo and Surveyor landing sites and photographed almost 100% of the lunar surface. Additionally, Lunar Orbiters acquired

¹At the inception of the Lunar Orbiter Program this office was designated Office of Space Sciences.
non-photographic data of three kinds: selenodetic characteristics of the lunar gravity field, radiation flux and frequency of micrometeoroid hits in the Moon's vicinity.

From August 1966 to October 1967 five Lunar Orbiters, each with two cameras, examined at very close range the Moon, which speculative theory and much scientific debate about its origins had enshrouded since Galileo had first observed the pockmarked lunar surface in the sixteenth century. The Lunar Orbiter Program also facilitated the initiation of manned exploration of the Moon. The role it played in doing this is the major subject of this history.

Together with Ranger and Surveyor, Lunar Orbiter has enabled scientists to extend their vision far beyond the limitations of earthbound and Earth-orbiting telescopes and radar. Three Ranger spacecraft transmitted live television views of the Moon as they raced towards impact points on its surface. Five Surveyors softlanded at different sites on the Moon and televised panoramic and close-up views of their immediate surroundings. In addition they tested the cohesiveness, bearing strength, color, and chemical composition of the lunar soil. Lunar Orbiter augmented the achievements of Ranger and Surveyor and provided data required by the Apollo Program for site selection and mission planning prior to the missions of Apollo VIII, IX, and XI.

NASA's unmanned three-program effort to explore the Moon also successfully fulfilled aspirations of many members of America's scientific community. One early spokesman for this community, Nobel Laureate
Harold C. Urey, had called for a stepped-up U. S. effort to explore the Earth's natural satellite in an address to the Lunar and Planetary Colloquium on October 29, 1958, at the Jet Propulsion Laboratory.

Urey summarized what scientists then knew about the origin and composition of the Moon: that much speculation but little conclusive knowledge existed on the Moon's environment. Man had noticed many unique and unusual phenomena on the lunar surface through optical telescopes since Galileo's first observations in 1609. Yet Earth's atmosphere limited the explorative abilities of scientists. Urey concluded that automated lunar probes would enable human observation to pierce the Earth's atmospheric constraints for more detailed, precise looks at the Moon. Such probes would allow man to take the next logical step before actual manned lunar missions brought him to the Moon's environment and an actual landing on its alien surface. That surface, unlike Earth, had not experienced millions of years of atmospheric erosion and weathering processes, as far as observations up to that time had revealed. What had it experienced? The answer to this question could possibly explain the birth and development of Earth and, indeed, of the solar system.\(^2\)

Following Urey's call for intensified efforts to extend America's lunar exploration capabilities, but not necessarily related to it, the newly created National Aeronautics and Space Administration requested the Jet Propulsion Laboratory to develop a study of the requirements for

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a multi-phase program to explore the Moon. Albert R. Hibbs, Chief of
the Research Analysis Section at JPL, organized a study group to analyse
the problem, and on April 30, 1959 he submitted the group's findings to
NASA Headquarters. Among other steps the Hibbs Report proposed placing
a lunar satellite:

in a well-controlled orbit around the moon using terminal
guidance. . . . High resolution photographs of the surface
of the moon will be taken at various wave lengths and po-
larizations. These photographs should provide information
on the surface characteristics of the moon that will be
valuable for choosing a site for a lunar soft landing.3

The 1959 Hibbs Report did not become the basis for NASA's Lunar
Orbiter Program. It indicated, nevertheless, the kind of probe which
would perform necessary, extensive photography of the Moon's surface.
The lunar orbiter concept later was adapted from the Surveyor Program
which NASA Headquarters had initiated with JPL in May 1960. The Ran-
ger Program began in December 1959 and
constituted the first phase in NASA's unmanned lunar exploration effort.
Surveyor, the second major program in this effort, originally envisioned
two kinds of probes: the Surveyor softlander and the Surveyor Orbiter,
each sharing common hardware, thereby theoretically reducing costs. Yet
as history would have it, Surveyor Orbiter did not materialize because
the Ranger and Surveyor Lander programs were overtaxing JPL manpower and
facilities.

In the wake of early Soviet space achievements the American space
program became enveloped in far-reaching political competition with the Soviet Union. In this atmosphere America counted heavily on the Ranger and Surveyor Programs, pioneering endeavors in the application of new technology, to achieve an urgently needed "first" in space. The failure of the first six Ranger missions between August 1961 and February 1964 heightened the tension, frustration, and anxiety among Americans about the state of U.S. technological prowess. By June 1964 the Congressional Subcommittee on NASA Oversight had reviewed the Ranger Program and concluded that:

... progress in improving testing and fabrication techniques at JPL is a step-by-step process with little direction from NASA Headquarters and that major improvement actions take place primarily as a result of failures. The subcommittee recognizes that the Ranger Program is both unique and complex in the strictest sense of a scientific accomplishment. However, the subcommittee does believe that increased use of systematic, thorough and pragmatic management and supervisory practices as currently in use throughout the missile-space industry would go far to develop improved testing and fabrication procedures needed for a sophisticated spacecraft such as Ranger.4

Since its inception in 1958 NASA had proceeded to develop new procedures in planning, organization and management as well as in hardware fabrication and in training for mission operations. In 1964 Congress had found weaknesses in one of NASA's lunar programs which demonstrated clearly some of the difficulties which NASA had to overcome in the development of new means for planning, building, and flying complex space probes. This task greatly challenged the knowledge and talent which

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NASA had thusfar mustered, but the muster took place in a politically charged atmosphere in which the United States had decided to pit its scientific and technological resources and prestige against those of the Soviet Union.

The history of the Lunar Orbiter Program constitutes a significant chapter in the initial exploration of the Moon and in America's first decade in space. It is part of the record of the preliminary phase in the Apollo Manned Lunar Landing Program, and we must now turn to its origins for a closer study of its role in putting the first men on the Moon on July 21, 1969.
As a major part of America's lunar exploration effort NASA initiated the Surveyor Program in May 1960 with a dual objective: to build an unmanned lunar lander for surface investigations and a lunar orbiter for photographic coverage of the Moon together with instrumentation to explore and measure its environmental characteristics. Both would use the Atlas-Centaur launch vehicle. NASA charged JPL with the responsibility of the Surveyor Program. JPL employed a philosophy similar to that which it had developed for Ranger, using a common spacecraft bus to carry out two different missions. By late 1961 NASA planners considered the idea of modifying the Surveyor-lander configuration to serve as an orbiter the most attractive approach. But at the same time the Office of Space Sciences reviewed the feasibility of a Surveyor-class orbiter. On December 5, 1961, Charles Sonnett, Chief of Lunar and Planetary Sciences at NASA Headquarters, requested Newton W. Cunningham, the staff scientist in his office, to compile an inventory of JPL's programs and a description of their current status. Specifically he wanted to know the stage of development of Surveyor Orbiter.¹

Cunningham responded quickly by describing the activities which JPL had been conducting since 1958 pertaining to a lunar orbital mission. These amounted to the following: (1) a 1958 study on close

photography of the Moon with a spacecraft launched by the Jupiter rocket; (2) the development of a unique camera system for Pioneer IV; (3) a study in 1959 for the Vega Program concerning instrumentation for a lunar probe in which a dual vidicon camera was to be used for obtaining low and high resolution photographs of the Moon; and (4) finally a study made in 1960 of a lunar orbiter photographic experiment. Cunningham pointed out that JPL scientists could not adapt the Ranger photographic system for use by the Surveyor spacecraft and that no photogram had been developed specifically for the long-life requirements of an orbiter. This was the general status of the Surveyor Orbiter at the beginning of 1962.

On March 23, 1961 the Lunar Sciences Subcommittee of the Office of Space Sciences had recommended that an orbiter be capable of achieving high resolution photography which could define objects smaller than 10 meters in size, of obtaining total photographic coverage of the limb area and of the farside of the Moon at a resolution of 1 kilometer, of performing reconnaissance photography of the lunar surface at 100 meters resolution and of making stereo pairs of areas where high resolution photography was planned. Cunningham's report showed that because of the Surveyor Orbiter Program's status as of early 1962 the Office of Space Sciences had hardly progressed to within reasonable sight of attaining

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2 Ibid., p. 2.


4 Cunningham, op. cit., p. 6.
these recommended objectives.

Concluding his memorandum to Sonnett, he briefly described the experiment proposals for the Surveyor Orbiter which his office had been receiving and noted that the proposed spacecraft would have a weight (about 2100 pounds) which would allow for several experiments in addition to the camera system. Unknown to Cunningham at this time the Apollo Program soon would place urgent requirements for data on lunar surface conditions with the Office of Space Sciences. Apollo needed these data in order to design hardware and missions. In doing this the Office of Manned Space Flight helped to reshape the philosophy on a lunar orbiter spacecraft within the Office of Space Sciences.

On June 15, 1962, the Office of Manned Space Flight submitted for the first time, since the U. S. manned lunar landing commitment, a formal list of requirements for data on the Moon's surface to OSS. This gave the Office of Lunar and Planetary Programs within OSS its first opportunity to compare the objectives of its contemporary lunar programs with Apollo needs. It re-examined the mission objectives of the Surveyor-lander and acknowledged that Ranger data would not meet the Apollo requirements.

It directed JPL to review all possible ways of converting the Ranger into an orbiter, but JPL scientists and engineers soon responded that a conversion was unfeasible. JPL, in turn, requested the Hughes Aircraft Company, prime contractor for Surveyor, to examine the possibility of designing an 800-pound orbiter which the Atlas-Agena Rocket could carry on a trans-lunar trajectory. Hughes's report showed that such a
lightweight spacecraft would only have a 60 pound payload which would place extreme constraints on the visual instrumentation system. Following this up, JPL examined the feasibility of using the Agena with a Surveyor Kick Stage which would allow for a spacecraft weight of 1200 pounds and a payload of 125 pounds. However, this approach would require more research and development before NASA could pass judgment on its feasibility. With little time to investigate this approach, the Office of Space Sciences proceeded with the Centaur-class Surveyor Orbiter.

By the end of July 1962 OSS had formulated the basic photographic requirements for the Surveyor Orbiter, but unfortunately these fell below the needs of Apollo for detailed data on lunar surface conditions. Apollo needed photographic data capable of showing slopes of less than $7^\circ$ with protuberances of less than one meter above the ground and depressions less than a meter below the surface on the front side of the Moon. The first version of the Surveyor Orbiter would be able to shoot stereoscopic photographs of the lunar surface with a resolution only as small as 30 feet and monoscopic photographs which would resolve details as small as three feet. It would cover a minimum area of $100^\circ$ longitude by $40^\circ$ latitude from the equator on the visible side of the Moon. The space-

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6 Ibid., p. 3.

7 Ibid., p. 7.
craft would most likely employ a television-type camera system. The Surveyor Orbiter photo system had one great drawback which Lee R. Scherer pointed out: "Landing area coverage of the size required by Apollo is not now possible except through repeated Ranger or Surveyor flights into the same area or by means of a photographic roving vehicle or a hovering spacecraft."\(^8\)

The state-of-the-art in photographic systems for long-life lunar missions had not progressed much beyond the Ranger system, and Scherer's recognition of this fact contrasted markedly to the status of the Surveyor Orbiter, on paper on July 20, 1962. Briefly summed up it was as follows:

1. Five flights were planned.
2. The Centaur rocket was to be the launch vehicle; the spacecraft would weigh approximately 1800 pounds.
3. The Jet Propulsion Laboratory was to establish design requirements and present them by September 1, 1962.
4. Surveyor Orbiter was to incorporate as much from the Surveyor Lander as possible in order to maximize the utilization of hardware and technology in the program.
5. By August 17, 1962, JPL was to develop a plan for the evaluation of experiments other than the Visual Instrumentation System which was unique. NASA Headquarters was to review this.
6. No Surveyor Orbiter Project Plan existed. JPL was to develop one and submit it for NASA review by November 30, 1962.
7. A total of $29.5 million in funds existed for the Surveyor Orbiter in FY 1963 and $29.0 million in FY 1964. These funds would be redistributed between Surveyor Orbiter, Surveyor Lander, and the Ranger Improvement Plan only on the

\(^8\)Ibid., p. 8.
basis of defined relative values.  

The Jet Propulsion Laboratory had no operational Surveyor Orbiter program at this time. Indeed the troubles which JPL was experiencing with the Ranger Program acted as a brake on the development of the orbiter.  

The Centaur Rocket Program compounded the problem at JPL. The Marshall Space Flight Center, in charge of Centaur, was experiencing development problems which had caused the rocket's delivery schedule to slip, moving the earliest date for the first launch of a Surveyor Lander to late 1964. Moreover, the Centaur difficulties motivated officials in the Office of Space Sciences to review Surveyor Orbiter plans with the objective of obtaining an orbiter independent of Centaur. The Office of Space Sciences began to examine the idea of a spacecraft which might use existing hardware and the Agena rocket, already successfully tested in space. By September 1962 OSS had the requirements for, and the feasibility of, a lightweight lunar orbiter under serious study. Nevertheless, it had one major technological obstacle to surmount: a flexible, long-life photographic system had to be developed, capable of obtaining data to meet the requirements established by the Office of Manned Space Flight.  

On September 21 Oran W. Nicks, Director of Lunar and Planetary Programs in OSS, requested Lee R. Scherer to form:  

a working group with appropriate representation from the Directorate of Lunar and Planetary Programs and  

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Interview with Oran W. Nicks, Director of Lunar and Planetary Programs, Office of Space Science and Applications, NASA Headquarters, August 14, 1967.
consultants from other Headquarters offices, the scientific community and Field Centers . . . to study adaptations of the Ranger and Able 5 spacecraft to conduct lunar reconnaissance missions beginning in 1964. . . .

Nicks asked Scherer to confine his activity to the known spacecraft systems: the Ranger, the Able 5 built by Space Technology Laboratories (STL), and a system proposed by the Radio Corporation of America (RCA).

At the same time A. K. Thiel, Vice President in charge of Spacecraft Systems Program Management at STL, sent a detailed summary of a proposed lunar photographic satellite to Nicks at NASA Headquarters on September 20. The STL proposal demonstrated for the first time the feasibility of a lighter-weight orbiter. The STL approach aimed at launching a spin-stabilized spacecraft into lunar orbit with the Atlas-Agena-D. Once there, the spacecraft's photographic system would take pictures of the Moon with a 100-inch focal-length spinpan camera very similar to that which Merton E. Davies of RAND had developed in 1958. The STL system did away with a cumbersome television payload and used a film system instead. Film had the definite advantage over television as far as obtaining higher resolution photographs. Thiel stressed the reliability of the STL proposal and stated that his firm would be prepared to build and launch three spacecraft within 22 months from the go-ahead date.

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10 Memorandum from Oran W. Nicks to Capt. Lee R. Scherer, OSS, September 21, 1962.

On October 15 Nicks informed Thiel that his office had the STL proposal under consideration. Meanwhile, within NASA, discussions continued concerning the priorities in the American lunar exploration program. The Office of Space Sciences and the Office of Manned Space Flight soon discovered that in order to expedite a manned lunar landing before 1970 they had to define more precisely their working relationship and the Apollo requirements which unmanned lunar probes could fulfill. On October 23, 1962, Joseph F. Shea, Deputy Director of the Office of Manned Space Flight, informed Nicks that OMSF had confirmed "the relative priorities which should be attached to the development of unmanned lunar systems for acquisition of data on the lunar environment in support of the manned lunar program".12

Shea also informed Nicks that the Apollo Program had a more urgent need for the kind of data which a softlanding Surveyor could provide than for that which an orbiter could obtain in the near lunar environment. The data which an orbiter could supply OMSF could directly apply to Apollo mission planning, but Surveyor data on the load bearing conditions of the lunar surface had direct applications in the design of the Lunar Excursion Module (LEM). Shea stressed that NASA should not commit itself to an orbiter in FY 1963 if this would jeopardize the present Ranger and Surveyor programs. In any case, if an orbiter could provide the manned lunar landing program with useful data, then it

12 Memorandum from Joseph F. Shea, Office of Manned Space Flight, to Oran W. Nicks, Office of Space Sciences, October 23, 1962.
should concentrate on selenodetic and topographical conditions of the Moon, data of which could permit the verification and selection of the initial sites for a manned lunar landing. 13

In pursuance of Shea's recommendation to Nicks to establish a better working relationship between the Office of Space Sciences and the Office of Manned Space Flight the directors—Homer E. Newell and D. Brainerd Holmes—respectively, announced the formal organization of the Joint OSS/OMSF Working Group with full-time representation from both offices. The group would be responsible for "recommending to OSS a program of data acquisition so as to assure a timely flow of environmental information into the planning for manned projects." 14

While the Joint Working Group initiated greater cooperative efforts between the two NASA offices, the work group under Scherer arrived at a decision on October 25 concerning its review of the studies for a lightweight orbiter. It recommended to Nicks that the STL proposal be given more intensive consideration and that NASA drop RCA's proposal. 15 Several major reasons supported the group's decision, and among them the Apollo requirements were the most important. As of November 16

13 Ibid.


these requirements stood as follows: an orbiter should be able to identify (1) 150-foot size objects over the entire surface of the Moon, (2) 15-foot size objects in the areas of prime interest, and (3) 4-foot size objects in the landing areas. 16

According to the Scherer group STL's orbiter seemed to have the greatest potential of fulfilling the requirements set by OMSF and OSS. The spacecraft would weigh approximately 700 pounds which placed it well within the Atlas-Agena launch vehicle capabilities. It would be spin-stabilized and its monopropellant propulsion system, capable of multi-starts, would give it the added flexibility of being able to change its orbital parameters around the Moon. This spacecraft could feasibly photograph the entire Moon from a polar orbit of 1000 miles above the lunar surface and obtain pictures resolving objects as small as 60 feet. If ground control placed the spacecraft in an equatorial orbit of 25 miles altitude it could photograph the area along the lunar equator at the amazing resolution of 1.5 feet. 17 The members of Scherer's group believed that these positive features far outweighed the drawbacks of the STL system.

On the other hand the RCA approach, which the group rejected, consisted of injecting a 3-axes attitude-stabilized payload into lunar orbit from a Ranger-type bus. The photographic system onboard would employ a vidicon television which had two major weaknesses: low

16 Ibid., p. 1.
17 Ibid., p. 2.
sensitivity in the vidicon unit and the need to develop better horizon scanners. In addition the capsule which the Ranger bus would inject into orbit would weigh a mere 450 pounds which left little allowance for actual payload hardware. The integration of the capsule and the Ranger bus and their separation before lunar orbit insertion further compounded the problem of weight limits on the payload. Even if this could be worked out with high reliability, the TV system could not resolve objects smaller than 400 feet in wide area coverage and 90 feet in limited area coverage at best.18

Scherer's group considered these negative aspects of RCA's proposal, together with the estimated cost of $20.4 million for building and flying only three spacecraft, prohibitive. The group believed that pictures of the lunar surface of equal resolution could be obtained by far less expensive means such as balloon-borne telescopes. The resolution limits of the RCA photographic system made the whole proposal too restrictive, and the group saw no reasonable, inexpensive way to overcome this fact within the near future.19 It turned instead to the STL proposal and recommended to Nick that NASA fund two STL studies in 1963 in order "to better establish the feasibility of the proposed Able 5 lunar photographic spacecraft . . . .," and "to provide more detailed information about the Able 5 spacecraft system and its photographic payload." Scherer's rationale for this decision was

18 Ibid.
19 Ibid.
stated as being "necessary to establish the confidence needed for duly considering a flight program of this type, should it be deemed preferable to a Centaur-based orbiter for any reason."\textsuperscript{20}

Plans for the Centaur-based lunar orbiter quickly began to lose their attractiveness once Scherer's group had decided that an Agena-class orbiter, based upon STL research, would give NASA a better means of data acquisition for Apollo requirements. Moreover the status of the Centaur Rocket Program, originally managed by the Marshall Space Flight Center and then transferred to the Lewis Research Center, made the Surveyor Orbiter concept even more unacceptable. Flaws in the rocket's basic fuel tank configuration and delays in the development tests had caused JPL to move back the date of the first launch of Surveyor A from late 1964 to early 1966.\textsuperscript{21}

In addition the Jet Propulsion Laboratory had encountered increasingly serious problems with the Ranger Program. These two facts and the added pressure resulting from Apollo needs supported the growing effort within the Office of Lunar and Planetary Programs to define and establish criteria for an Agena-class lunar orbiter program.

Without the knowledge of the Scherer group's findings, Clifford I. Cummings, JPL Lunar Program Director, informed Oran W. Nicks on October 26 that JPL was planning to undertake yet another study of

\textsuperscript{20}Ibid., p. 1.

\textsuperscript{21}Memorandum, Dr. Homer E. Newell, Office of Space Sciences, NASA Headquarters, November 1, 1962.
the Surveyor Orbiter and its mission. He stated that JPL desired to spend $1.5 million of its FY 1963 budget to do this work, and he included in his memorandum to Nicks a proposed plan of study for a lunar orbiter spacecraft. Nicks immediately answered the JPL request in a letter to Cummings in which he outlined the numerous study efforts already performed or in the process of completion. He pointed out the concern of NASA Headquarters about the growing disparity between the status of the Surveyor Program at JPL and that of the Centaur Rocket Program, and informed him that Headquarters had already proceeded to examine the feasibility of an Agena-class orbiter. An additional and costly study had no place in the present scheme of things, especially when JPL was experiencing difficulties with the Ranger Program.

The failure of the first four Ranger missions in 1961 and 1962 to obtain photographic data from the Moon and the total commitment of the Jet Propulsion Laboratory to the Ranger and Surveyor Programs had motivated NASA Headquarters to approach Floyd L. Thompson, Director of the Langley Research Center, in mid-1962 with the request that his center seriously consider the management of a lunar orbiter program. Unlike JPL, Langley had never undertaken a major space flight

22Memorandum from Clifford I. Cummings, Director of Lunar Programs, JPL, to Oran W. Nicks, Director, Office of Lunar and Planetary Programs, NASA Headquarters, October 26, 1962 and memorandum in reply from Oran W. Nicks to Clifford I. Cummings, November 8, 1962, p. 2. See also Brief History of Lunar Orbiter Work, prepared for Cortright May 2, 1963.
project, and Thompson willingly accepted the task of reviewing Langley's facilities and capabilities to assess whether or not it could actually manage such an operation.

While this activity was being conducted Oran W. Nicks assigned Scherer to form another work group with Eugene Shoemaker, a geologist on loan to NASA from the United States Geological Survey. They were to define more exactly than had been done thus far the Apollo requirements for the photographic data which an orbiter could best provide. Scherer and Shoemaker organized a small staff of men to assist them in carrying out this task, and they spent the remainder of 1962 and early 1963 examining Ranger and Surveyor spacecraft components which might best be used in a lightweight orbiter. Concurrently Dennis James of Bellcomm, a private research and advisory organization working for OMSF, conducted another review of existing lunar orbiter technology and hardware late in 1962.

In October 1962 the Office of Space Sciences had followed up the recommendation of the first Scherer group in a further move to define the requirements for an Agena-class orbiter and had let a contract with the Space Technology Laboratories to "make a detailed preliminary study of a spin-stabilized lunar photographic spacecraft based upon the Able 5 development to be launched by the Atlas-Agena vehicle." 23

In October 1969, the Office of Space Science and Following on the
recommendations of the fine Science Group in a manner more to
fit the recommendations for American-type models for competition
with the French-French concept of "make a generally piloted
Le Monde of September 1969, a transatlantic conceptual
expedition in Africa and Europe named "African Years of Space"

The Office of Space Science of the National Aeronautics and Space

Administration, Office of Space Science.
STL conducted the study, and during a major planning and review meeting at Langley on February 25, 1963, held by representatives from OSS, OMSF, Bellcomm, STL, and Langley, presented the preliminary conclusions of its research. As a result of the Langley meeting NASA Headquarters stepped up activities to formulate a viable philosophy for an Agena-class orbiter. Space Technology Laboratories continued work on a reliability assessment of a lunar orbiter photographic mission and analysed the problem of having a lunar orbiter locate a landed Surveyor. Dennis James of Bellcomm developed a study for Shea and Scherer of the role which a lunar orbiter could play in the manned and unmanned exploration of the Moon. 24

Meanwhile personnel at the Langley Research Center examined the same problem area which STL was exploring independently. On March 5 STL representatives presented their findings to a second meeting at Langley of people from that center, from OMSF, OSS, and Bellcomm. 25

Amazingly the two independent analyses came to very similar conclusions. First, the probability factor of one mission success out of five attempts was approximately 93/100. The probability of two successes in five was found to be about 81/100. In addition the studies


25 Memorandum from Homer E. Newell, Director, Office of Space Sciences, to the Director, Office of Space Flight, concerning questions on unmanned lunar orbiter, March 14, 1963.
confirmed that an orbiter using existing hardware could photograph a landed Surveyor and thus definitely assist in Apollo site verification. Relying upon these data the members of the meeting concurred that an unmanned lunar orbiter had an extremely important role to play in the pre-Apollo phase of the Moon's exploration. The next major step was to convince top Headquarters management that an Agena-class orbiter could best accomplish exploration for both the Office of Space Sciences and the Office of Manned Space Flight. To this task OSS and Langley officials now turned.

During the course of February and March the Scherer-Shoemaker group worked intensively with the Langley Research Center to formulate a project approval document for a lightweight Agena-class orbiter. The contributions made by Bellcomm, Space Technology Laboratories, and Langley aided Scherer in constructing the basic guidelines for a new lunar orbiter program. By March 25, 1963, this had resulted in the preliminary Project Approval Document together with a procurement document. Floyd L. Thompson and Sherwood L. Butler, Langley Contracting Officer, submitted these to Dr. Robert C. Seamans, Jr., on this date. At about the same time, Langley finished a preliminary Project Development Plan which it sent to Dr. Newell's office.

at the end of March.\textsuperscript{27} NASA needed to know precisely what it wanted a lunar orbiter to do; therefore, Bellcomm continued to define lunar orbiter objectives during the spring of 1963. This information would enable the Office of Space Sciences to draw up a request for a proposal document which it could submit to select firms in the aerospace industry.

During the first week in May Bellcomm disclosed in a working paper that "there are at the moment no fully developed lunar orbiter systems."\textsuperscript{28} Subsequently it submitted a document entitled "Orbiter Recommendations" to Scherer in OSS. He reviewed and forwarded it to Clinton E. Brown at Langley with the statement that "although the specific recommendations are subject to change on review by the Office of Space Sciences, it is considered an excellent document for guidance of Langley Research Center in preparation of the Request for Proposal for the Lunar Orbiter."\textsuperscript{29} This set the stage for work on the RFP document while, at the same time, Oran W. Nicks briefed Dr. Robert C. Seamans, Jr., on the initiation of the new lunar orbiter program and its impact

\textsuperscript{27}Project Development Plan for Lunar Orbiter Project (updated December 1964 and June 10, 1966), Langley Research Center, Project No. 814-00-00, p. II-2.


\textsuperscript{29}Letter from Captain Lee R. Scherer, NASA Headquarters, to Clinton E. Brown, Langley Research Center, May 24, 1963.
on the Block V Ranger series of spacecraft.  

Meanwhile the Office of Manned Space Flight submitted a summary of the Apollo requirements to OSS. It stated the critical needs: (1) data on radiation flux over a typical two week period; (2) a summary and analysis of all efforts for short term prediction of severe solar proton events; (3) data of measurements of particles capable of penetrating 0.01-centimeter and 0.1-centimeter aluminum during an average and a peak two week period of micrometeoroid activity; and (4) photographic data on lunar surface conditions capable of showing cones 3.5 meters high and slopes of 15° inclination in an area of 60 meters radius, prior to the fall of 1965, and thereafter equivalent data showing cones of 50 centimeters height and slopes inclined 8° in an area of 1600 meters radius. Other major needs were: (1) the measurement of the distribution of slopes greater than 15° of areas 7 meters in diameter; (2) photographs of at least 25 meter resolution over the largest possible area within ±10° latitude and 0° to 60° west longitude.  

While the Office of Manned Space Flight and the Office of Space Sciences coordinated their needs through the Joint Working Group, Langley officials hammered out the Request for Proposal document and the requirements of a lunar orbiter contract. As part of this effort


31 Summary of OMSF Data Requirements Document, no date. See also: Discussion of Lunar Surface Photographic Requirements, Appendix III, April 19, 1963.
representatives from NASA Headquarters met with officials at Langley on June 25 to agree upon the type of contract to be utilized in the procurement of the Agena-class lunar orbiter. The position taken by Headquarters was that the contract should employ a fixed-cost-plus-incentive mechanism similar to that used in the Pioneer Program. Langley officials, on the other hand, desired the cost-plus-fixed-fee contract because they expected unknown development problems to arise and felt that such a contract would be easier to administer in that case. Extensive discussion and debate brought the two groups to a compromise solution which would use the cost-plus-incentive-fee contract for procurement. Preliminary incentives were also established, but the NASA officials left room for further suggestions from potential contractors.32

As part of the discussions between Headquarters and Langley, Homer E. Newell sent a statement on July 1 to Floyd L. Thompson, Director of Langley, in which he further clarified the Headquarters position on Lunar Orbiter and its objectives. Thompson had expressed some concern that the proposed orbiter objectives might be greater and more sophisticated than Langley had first estimated. Newell explained that his office maintained a policy of giving the needs of the Office of Manned Space Flight maximum support as far as such did not impinge upon OSS goals. At the present time the specifications in the Office of Space Sciences for a lunar orbiter could be

32Memorandum to SL Files from SL/Assistant to the Director for Manned Space Flight Support, Subject: Meeting on Incentive Contracting for Lunar Orbiter at Langley Research Center - June 25, 1963, June 26, 1963.
approached but not entirely reached by an Agena-class orbiter. Bellcomm's studies had developed objectives for a lunar orbiter which would not fully satisfy Apollo requirements; but Bellcomm's review of the STL proposal showed that these objectives represented the existing limits of feasibility. Although the proposed high resolution photography capable of pinpointing a landed Surveyor seemed to be beyond feasibility, Langley did not have to rely entirely upon the Bellcomm work to make a decision. Instead it could use the Bellcomm studies as a reference for determining what kind of Agena-class orbiter could accomplish such an objective and thus satisfy OMSF-Apollo requirements.

Newell asked Thompson for alternative suggestions to his policy of supporting OMSF-Apollo needs if it were too impracticable for Langley. During July Langley continued work on the Request for Proposal and sent several documents pertaining to it to the Office of Space Sciences in Washington for review and approval. NASA Headquarters returned comments on parts of the Langley RFP to that center with its recommendations. First it desired that the Request for Proposal indicate to bidders that NASA was going to insist upon working closely with the winning contractor in selecting and approving subcontractors for the photographic data acquisition components. NASA would reserve the right to determine the selection of the manufacturer of the sensor in the spacecraft system in order to obtain the best sensor regardless

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33 Memorandum from Dr. Homer E. Newell, Director of the Office of Space Sciences, to Dr. Floyd L. Thompson, Director of the Langley Research Center, July 1, 1963.
of any relationship between the prime and the subcontractors. \(^{34}\) Secondly NASA Headquarters wanted the Statement of Work to indicate that it favored a spin-stabilized spacecraft. NASA knew through studies that a spin-stabilized system was feasible, simpler, and less expensive than an attitude-stabilized system. Since the Space Technology Laboratories had already conducted research on a spin-stabilized lunar photographic probe, other bidders might feel that STL had an undue advantage over them. Thus the RFP should make explicitly clear that a spin-stabilized system, if strongly justified, would be acceptable. This would influence more bidders to concentrate on spin-stabilization. \(^{35}\) Also, if bidders could offer approaches which differed from the established specifications but would result in substantial gains in the probability of mission success, reliability, schedule, and economy, then NASA certainly invited them to submit such alternatives.

NASA Headquarters wanted the RFP to clarify in no uncertain terms that the main mission of the new lunar orbiter was the acquisition of photographic data of high and medium resolution for selection of suitable Apollo and Surveyor landing sites. Secondary objectives supplementing this would gather selenodetic data on the size and shape of the Moon and on the properties of its gravitational field. Moreover, the orbiter would measure certain other lunar environmental characteristics in the vicinity of the Moon. However, the RFP was to state

\(^{34}\) Headquarters Comments on Documents for the RFP of the Agena-class Lunar Orbiter, no date, p. 1.

\(^{35}\) Ibid., p. 2.
clearly that under no circumstances would these secondary objectives be allowed to dilute the major photo-reconnaissance mission. For this reason the Statement of Work would not give detailed descriptions of them.

In outlining the photographic requirements which the RFP was to make explicit, NASA Headquarters counseled Langley to use the following guidelines for identifying cones and slopes on the lunar surface. Cones were assumed to be circular features at right angles to a flat surface. These could be said to be recognized if the standard deviation of the cone's estimated height caused by system noise in the spacecraft were less than 1/5 of the cone's height. Slopes were assumed to be circular areas inclined with respect to the plane perpendicular to local gravity. Again a slope would be considered recognized if the standard deviation of estimated slope caused by system noise were less than 1/5 of the slope.36 The orbiter would need at least two photographic modes in order to obtain these data: high resolution of limited areas and wide coverage at medium resolution, and this requirement had to be fulfilled in any bidder's proposal. However, a contractor would not have to employ both modes of photography on any one mission.

Moreover, the Request for Proposal had to state clearly that a bidder would provide in his proposal instrumentation and telemetry capable of measuring certain characteristics of the lunar environ-

36 Ibid., pp. 7-8.
ment. These components would have to function independently of the photographic system in order to record data regardless of the success or failure in obtaining photographs. Among the various environmental conditions which might be measured, micrometeoroid flux and total exposure to energetic particles and gamma radiation were two whose measurement would be necessary for gauging the performance of the spacecraft while also providing vital data for the Apollo Program. In addition to this instrumentation the bidder would have to be able to determine precisely the altitude of his spacecraft at the time of each photographic exposure, the orientation of the picture in relation to lunar north, and the relative angle of the sun to the portion of the Moon's surface covered by any photograph. The bidder would have to demonstrate his capability for providing such data as would be necessary to position all points within an area of contiguous coverage while being able to pinpoint 90% of all well-defined points to within 100 meters of their true horizontal positions relative to each other in the high resolution mode. Finally, the bidder would be required to locate all photographed areas to within one kilometer of their correct position in the lunar coordinate system.  

In conclusion NASA Headquarters wanted a Request for Proposal document so explicit that when it presented it to the aerospace industry any bidder would understand exactly what NASA wanted - nothing more, nothing less. Headquarters defined what it desired that the

37 Ibid., pp. 11-12.
RFP do as precisely as possible so that Langley succeeded with little difficulty in formulating a very good document. By August 1 Langley was concluding its preparation of the RFP. It had also agreed to a cost-plus-incentive-fee contract with the incentives based upon cost, delivery, and performance.38 Late in August Scherer presented a summary of the RFP to Nicks and Cortright, and on August 30, after Dr. Robert C. Seamans, Jr., had reviewed the RFP, NASA released it to the potential bidders which it believed could best conduct the new Lunar Orbiter Project.39 This step officially initiated the program.


NASA's new Lunar Orbiter Program began in a climate of tension and hope. Congress provided the source of tension, and the aerospace industry appeared hopeful. Top NASA officials had waged an impressive fight for more funds for an orbiter during August 1963 authorization hearings on Capitol Hill. The House Committee on Appropriations had taken NASA to task for failing to initiate the Surveyor Orbiter Project, funds for which Congress previously had appropriated. The Committee claimed that NASA had channeled much of the money into projects apparently of a higher priority, and that it had spent almost nothing on the Surveyor Orbiter. The Committee seemed to think that NASA's lack of progress on its original concept of the Surveyor Orbiter and its development of a new lunar orbiter concept for a different project meant that it did not consider the mission of an orbiter as important as it wished Congress to believe.

Seamans, Dryden, Newell, Cortright and Pickering all provided testimony to clarify NASA's position on the Surveyor Orbiter and the urgent need for a lightweight lunar orbiter which could obtain vital data for the Surveyor Lander and the Apollo Programs. After their testimony before the Senate Committee on Aeronautical and Space Sciences, the Senate restored the proposed funds of $28.2 million for FY 1964 for an orbiter, which the House

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had deleted from its authorization bill. Both houses reached a compromise late in August and authorized a total of $20.0 million for an orbiter.  

Appropriation hearings pertaining to the lunar orbiter project were scheduled to begin on October 18, but the Office of Space Sciences relied upon the approved authorization as a reasonable assurance that funds would not evaporate after the Lunar Orbiter Program had gotten under way.

With the Request for Proposal already sent out, the fledgling Lunar Orbiter Project Office (LOPO), under the direction of Clifford Nelson, set up shop at the end of August in the Langley Research Center's nineteen-foot wind tunnel facility. The members of the original LOPO nucleus besides Nelson were: Israel Taback, Robert Girouard, William I. Watson, Gerald Brewer, John B. Graham, Eugene A. Brummer, Robert Fairbairn, and Anna Plott, the latter conducting all secretarial tasks single-handedly. William J. Boyer joined the group soon after its formation, and its members quickly tackled the job of formulating work statements. Next they drew up a preliminary program schedule and organized evaluation teams for the proposals which bidders had to submit on or before October 2.

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At NASA Headquarters Captain Scherer, the Lunar Orbiter Program Manager, issued his first status report to Oran W. Nickis and Homer E. Newell on September 4 and stated that Seams had signed the Project Approval Document (PAD) on August 30. It called for five flight spacecraft using the Atlas-Agena D launch vehicle. The program would rely on the tracking and data acquisition facilities of the Jet Propulsion Laboratory which consisted of the Deep Space Network (DSN) and the Space Flight Operations Facility (SFOF). In conclusion the report stated that the Langley Research Center was managing the Lunar Orbiter Project as its first big space flight venture.  

NASA's decision to build a new lunar orbiter delighted various aerospace firms engaged in research and development for the American space effort. While Congress questioned and the Office of Space Sciences continued planning, five major aerospace companies began developing proposals in the hope of submitting the winning bid for the new spacecraft.

Hal Taylor, writing in the industry-oriented journal Missiles and Rockets, claimed that NASA's decision to "switch from the heavier Surveyor Orbiter -- to be launched by Centaur -- was made because the Atlas-Agena is cheaper than Centaur." He added that "the Surveyor Orbiter and the Surveyorsoftlander were both scheduled for launch in the same time period, putting them in competition with each other."  

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Taylor had gained his information in an interview with Scherer shortly after NASA had approved the new Lunar Orbiter Program. During that interview he had learned that the lunar orbital mission constraints precluded the use of a modified Ranger. Scherer had explained to him that "Ranger's retro-rocket system is too small to brake the spacecraft into orbit and that it is not thermally designed for an orbiting type mission." These factors coupled with the outstanding failures of the first five Ranger flights and the development problems of the Centaur Rocket had necessitated a fresh start in the effort to obtain vital photographs of the lunar surface.

In Aviation Week & Space Technology, another major aerospace periodical, Richard G. O'Lone briefly surveyed the nature of NASA's Lunar Orbiter contract. He stated that the Lunar Orbiter program was to be "the first major National Aeronautics and Space Administration project that will include cost, delivery and technical performance incentives as part of its contract." O'Lone stressed that "selection of the orbiter as its first major incentive venture illustrates the urgency NASA attaches to the program." In addition NASA included substantial incentives based upon predetermined rates for all under-

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6Ibid.
8Ibid.
runs and penalties for overruns on deadlines. These it had made explicit so that the contractor would know exactly the limits within which he could work.

However, NASA officials had been quick to state that the Lunar Orbiter incentive contract did not "mean that NASA has shifted its emphasis from a firm's technical management ability to the price it quotes for a job."\(^9\) More significantly for Lunar Orbiter "incentive contracting compels both NASA and the contractor to define what they want at the earliest practical date."\(^10\) This was exactly NASA's intention with the Request for Proposal document, and the aerospace companies bidding for the contract had to reflect in their proposals a well defined understanding of the RFP.

While the potential contractors developed proposals for a lunar orbiter spacecraft NASA's Office of Lunar and Planetary Programs accelerated the planning for the new lunar exploration venture at Headquarters and Langley. Oran W. Nicks called together Floyd L. Thompson, Clinton E. Brown, Clifford Nelson, Charles Donlan, Eugene Draley, and Harold Maxwell from the Langley Research Center for a conference at NASA Headquarters on Tuesday, September 11, to discuss at length the major management aspects of the program. Lee R. Scherer and Leon Kosofsky, the Program Engineer for Lunar Orbiter, also attended.\(^11\)

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\(^9\)Ibid.
\(^10\)Ibid.
\(^11\)Memorandum from Captain Lee R. Scherer to his Record, September 20, 1963.
Nicks believed that Headquarters and Langley had to maintain a well defined, firm understanding on major policies to ensure the success of the whole undertaking. He sought from the beginning, through meetings such as this, to establish strong links of communication between the two groups in order to expose and resolve any problems quickly rather than allowing them the opportunity to snowball into a major crisis for the program.

During the course of September the Lunar Orbiter Project Office at Langley established the Source Evaluation Board (SEB) which it divided into several teams of experts who would analyse every contract proposal which they received. As an important part of the SEB LOPO formed the Lunar Orbiter Proposal Scientist Panel to consider the scientific merits of each bidder's approach. The members of this key reviewing group were: Clinton E. Brown and Samuel Katzoff from Langley, Jack Lorell from the Jet Propulsion Laboratory, Normann Ness from the Goddard Space Flight Center, Bruce Murray from the California Institute of Technology, and Robert P. Bryson from NASA Headquarters. They helped to lead the critical phase of proposal analysis which began early in October and lasted more than six weeks.

Of the score of possible aerospace companies which seemed to have the capability to carry out the objectives of a lunar orbiter program

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five submitted contract proposals. To better understand the significance of the spacecraft which NASA finally chose, it may be useful briefly to summarize the five choices industry presented. As the first of the five the Hughes Aircraft Company entered the competition with an impressive record. The Surveyor systems contractor for JPL, Hughes was no newcomer to the field of spacecraft design and fabrication. Its proposal centered around a spin-stabilized spacecraft. However, the SEB analysis of Hughes's approach revealed several important weaknesses in the proposal. First, while spin-stabilization greatly simplified the problem of attitude acquisition and control it placed disadvantages upon the photographic, power, and communications systems. Several inherent drawbacks in the photographic system, which would require extensive development before it could be incorporated into the spacecraft, added to this.\textsuperscript{13}

The insufficiency of the power system to supply the necessary electricity to drive the other systems proved to add a second negative aspect to the Hughes proposal. The SEB had found that the design did not provide enough solar cells to produce the required electrical energy, and that if more were added, Hughes would be forced to change the configuration of its spacecraft. In addition to this the proposal had given an incomplete description of the communications system, leaving out items which NASA had specified in the RFP. Finally, the SEB concluded that

\textsuperscript{13} Memorandum for Lunar Orbiter Contract File, Subject: Debriefing of the Hughes Aircraft Company, Culver City, California, January 21, 1964, Langley Research Center, Hampton, Va.
the solid-fuel retrorocket for deboosting the spacecraft into lunar orbit was inadequate to alter the parameters of the orbit around the Moon. All of these factors, when taken together, constituted too great an element of unreliability, and this plus the development problems outweighed the strong points centering around spin-stabilization.

The only other proposal for a spin-stabilized lunar orbiter came from Thompson Ramo Wooldridge/Space Technology Laboratories of Redondo Beach, California. The TRW/STL orbiter counted on spin-stabilization to reduce the critical problem of attitude control. Unfortunately, this meant that it had to make the other major systems compatible with spin-stabilization. This put severe restraints on the photographic system which would have to employ fast shutter speeds and a high speed film very susceptible to radiation fogging. The use of a liquid developer in the film processing system also presented greater risks than would accompany other existing photographic systems. Moreover, due to the absolute necessity to maintain constant image-motion compensation, the quality of resolution of a single exposure might vary considerably from one side of the film to the other. Worse yet, the proposed format of a single photographic frame would be too narrow, requiring the camera to make a large number of frames of any given area of the lunar surface.¹⁴

If the TRW/STL photo-system was impractically elaborate, the pro-

posed communications system simply failed to meet the requirements of the NASA RFP. Neither the communications nor the power systems were capable of performing their functions for the minimum thirty-day spacecraft life span. Due to spinning, the solar panels of the orbiter could not produce adequate quantities of power at any given time to recharge the spacecraft's battery. Moreover, the capacity of the battery was such that it could not have accepted a greater recharging rate than it already had even if the energy producing area of the solar panels were enlarged. This amounted in the final analysis to a proposal with too many areas open to critical development problems. NASA wanted a lunar spacecraft which would require as little development of systems and as much use of off-the-shelf hardware as possible. 15

While Hughes and TRW/STL could boast of experience in the increasingly complex realm of designing, building, and flying automated space probes, the Martin Company, which offered a third approach, had no such advantage in this respect. However, it presented a very satisfactory proposal from the standpoint of technical feasibility. Unlike the first two firms, Martin designed its orbiter to employ three-axis stabilization to serve as a platform from which a very well-designed photographic system could easily take pictures of the Moon without having to compensate for rate of spin. Although it had a limited capability to perform high quality convergent stereo photography, its film processing, readout, and communications systems appeared to be

15 Ibid.
highly capable of returning data back to earth in a very short time. This aspect of the Martin proposal greatly pleased the SEB evaluators at Langley. On the other hand, the Martin orbiter lacked redundant systems which would ensure greater reliability in spacecraft performance, and the proposed solar panels seemed to the SEB somewhat fragile for the task of supplying energy to the spacecraft.16

Martin's proposal showed its most serious weaknesses in the areas of launch and flight operations and the use of the tracking and data acquisition facilities. The proposal stressed launch operations procedures over flight operations, and the description of both was ambiguous. Moreover, Martin had failed to include an integrated trajectory plan of the functions and responsibilities of NASA, Martin, DSIF, and SFOF personnel. Finally, due to its limited amount of experience in spacecraft design and fabrication, Martin would necessarily have to rely upon subcontractors, and this could present NASA with major difficulties should relations between Martin and its subcontractors become disturbed. This, according to the SEB, made the Martin proposal the least manageable of the five.17

The two remaining bidders, the Lockheed Missiles and Space Company and the Boeing Company, presented the Source Evaluation Board with an interesting challenge. The former had long years of experi-


17 Ibid.
ence in designing and building the Agena system for the U. S. Air Force. Indeed, its Agena had served USAF well as a platform in Earth orbit for reconnaissance photography around the globe, and the rocket and photographic systems were well mated, making a very efficient spacecraft. Logically Lockheed proposed to convert this to an orbiter which would consist of the Agena with integrated photographic, power, communications, and attitude control systems. Lockheed stressed that the Agena had been proved in space and would require only minor modifications. This would make it unnecessary for NASA to buy a new, untested spacecraft.18

The Boeing Company, on the other hand, could not make such a boast since it had never managed a major space flight program. Aircraft manufacture was Boeing's big business, but competition in the aerospace industry had forced the Seattle-based firm to turn towards space projects and to invest in new capital equipment in order to meet and excel in the increasingly competitive world of rocket research and space exploration. Indeed it was just finishing its new Kent Facility for testing spacecraft under simulated space environmental conditions, and this would enable it to conduct its own testing without costly delays caused by the necessity to send equipment out to be tested elsewhere. Thus a lunar orbiter program would inaugurate Boeing as a major producer of automated space probes.

Looking at the Lockheed proposal and also at that from Boeing, the Source Evaluation Board saw the facility with which the former might be implemented and realized that the latter bidder lacked experience in spacecraft design and fabrication. But the Lockheed proposal had some serious flaws which outweighed the attractive possibility that NASA might be able to obtain a ready-made orbiter.

First, the existing Agena system was designed for Earth orbit, and it had proved its ability to perform very well. But sending a spacecraft some 240,000 miles into space and putting it into an orbit around the Moon was an entirely different prospect, and the configuration of the Lockheed orbiter presented special problems related to this. A lunar orbiter would be useless if it could not orbit the Moon precisely as NASA scientists and engineers desired it to do. Moreover, any orbiter would be a waste of money if it could not perform exactly the photography which NASA required and do this by using the best possible means afforded by existing technology. The SEE believed that the use of any outmoded or incompatible hardware for such critical work would squander valuable NASA funds.

This being the case, it found the concept of sending a modified Agena rocket to do lunar orbital photography too impracticable because the Lockheed orbiter presented the extreme difficulty of deboosting the heavy deadweight Agena into a lunar orbit. Even if deboosting were accomplished the kind of orbit such a spacecraft could attain would create severe restraints for photography. NASA would have to go to unnecessary
trouble to obtain the vital photographic data of the lunar surface, and this fact made the Lockheed proposal much less attractive.19

Yet the SEB found the Lockheed photo system to be almost ideally suited to its task. It was a space-proven package with the capability of performing high quality stereographic photography. However, the proposed processing and readout systems would require more development before Lockheed could use them in an orbiter, and this meant extra time and funds to accomplish basic development work. Even so, the major negative factor of the Lockheed orbiter still remained the necessity to carry the heavy deadweight of the burned-out Agena to the Moon; this would require extra fuel to control the useless bulk in lunar orbit. Hardly any of the Agena's weight would be directly involved in vital mission activity, and yet its presence would definitely affect orbital parameters and spacecraft velocity to the extent of reducing the versatility of the orbiter as a photographic platform. This disqualified the Lockheed approach.

Finally the SEB turned to the proposal of the Boeing Company. The Seattle-based aerospace firm presented an orbiter concept which used a three-axis stabilized spacecraft weighing only 800 pounds and using much space-tested off-the-shelf hardware. For example, Boeing would have a photographic system fabricated by Eastman Kodak, the contractor for the Agena photo-system already in use by the U. S. military. Film processing onboard the orbiter would be handled by the Kodak Bimat process which had been perfected. The Boeing orbiter would use the same

19Ibid.
Canopus sensor for acquiring the star Canopus as an attitude reference point as used on the Mariner C spacecraft. The Marquardt rocket engine for deboosting the spacecraft into lunar orbit would be the one developed for the Apollo Program. Four large solar panels would generate the power for the spacecraft, and these would be backed up by nickel-cadmium batteries which would supply electrical energy at the times when the orbiter would be out of sight of the Sun. The whole system would generate 266 watts of electrical output to power the spacecraft's vital functions.  

Boeing's proposed photographic system pleased the Source Evaluation Board because it offered greater flexibility than those submitted by the other four bidders. It was a scaled-down version of the Eastman Kodak system used by the Air Force, and, unlike the others, it featured two cameras which could take pictures simultaneously -- one using a high resolution, the other a medium resolution mode. On a single mission the Boeing orbiter could photograph a greater area of the lunar surface and also obtain more detailed photographic data than any other proposed system. The photo package would be capable of providing pictures of areas up to 8000 square kilometers in the high resolution mode -- four times the size of area called for in the NASA Request for Proposal. Moreover, the photographic payload would use the very suitable, highly perfected Kodak Bimat process to develop and fix the film onboard the spacecraft. It is, therefore, important to the understanding of the Boeing lunar orbiter concept to survey briefly the photographic system and the Bimat process.

to recognize the greater degree of flexibility which these two integrated items offered NASA.

The Eastman Kodak photographic system eventually incorporated into the Boeing orbiter was not new, and, unlike the other four firms which had submitted their bids, Boeing did not have to build its spacecraft's payload from scratch. Indeed the basic system which Eastman Kodak would provide Boeing had been in existence since mid-1960 when Kodak had designed and built it for military applications. The mechanics of the system were as follows: Film from a supply reel passed through a focal plane optical imaging system, and controlled exposures were made. Once past the shutter, the film underwent a dry chemical developing process and then entered a storage chamber. From here it could be extracted upon command from the ground for scanning by a flying spot scanner and then passed on to a take-up reel. The scanning device consisted of a cathode-ray tube with a rotating anode having a high-intensity spot of light. The scanner optics of the moving lens system reduced by 22 times this point of light, focused it on the film transparencies, and scanned them. A photomultiplier then converted the light passing from the scanner through the film into an electrical signal whose strength would vary with the density of the emulsion layer on the film. This signal would then be transmitted to a receiving station on Earth and reconstructed. Eastman Kodak would upgrade for the demands of the Boeing orbiter and its mission.

A significant part of the improvement in the system was the introduction of the Kodak Bimat process which eliminated the necessity for using a "wet" developer on the film. Instead a film-like proces-
sing material was briefly laminated to the exposed film to develop and fix the negative image and, if the need existed, to produce a positive image. In the case of the Boeing orbiter this second step was not used, and only negatives were made. Once the film had been developed and fixed the Bimat material separated from the film and wound onto a storage spool. Kodak's "dry" process offered the photographic system of the Boeing orbiter very positive advantages over those of the other bidders. Besides eliminating the need for liquids and their storage containers, Bimat did away with the necessity of an extra fixing step while producing photographic negatives having normal, high-quality physical, sensitometric, and image characteristics. This greatly simplified the problems involved in materials-handling while making the whole process fully automatic. Moreover, every part of the film enjoyed fresh processing chemistry which made the resulting negatives more consistent and uniform. Bimat would not leave any crystalline deposit of the film after separation, and lamination of the two materials would not result in any damage to the emulsion layer. In addition the position of the equipment would not affect processing of the film, a factor which made the Bimat process ideally suited to work in a space environment.

Yet the Boeing-Eastman Kodak photographic system was not the only strength of the proposal. Boeing also demonstrated a very real under-


22 Ibid.
standing of the relationships of the various phases of the program to one another as detailed in the NASA Request for Proposal and clearly expressed a willingness to cooperate with NASA and to keep a nucleus of full-time personnel managing key areas of the program from go-ahead to conclusion of the final spacecraft's mission. Proven technical competency, flexibility and imagination, sound planning and organizational management, wide use of space-tested hardware in the spacecraft design, reliable test facilities, and the absence of any major development tasks or the need to rely heavily on subcontractors made the Boeing Company's lunar orbiter proposal the most realistic, manageable, and potentially successful of the five.

The NASA-Langley Source Evaluation Board overwhelmingly graded Boeing's proposal as the one most likely to fulfill the objectives of the Lunar Orbiter Program and to cost the least per photograph returned to Earth. There had been some debate about accepting the high priced Boeing system rather than that of Hughes, but Floyd L. Thompson, Director of Langley, shrewdly stressed that the Boeing system was the only one which offered sufficient safety to the film against fogging caused by solar flares. None of the other bidders had adequately recognized the danger of solar radiation to a long-life mission. He pointed this out to NASA Headquarters officials who reviewed the work of the SEB. As a result Headquarters approved Langley's request to negotiate a contract with the Boeing Company of Seattle, Washington.

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NASA CHOOSES BOEING TO BUILD LUNAR ORBITER

The first months of 1964 saw stepped-up activities to integrate Lunar Orbiter Program planning with contractor needs and establish requirements which various NASA centers and other government agencies could fulfill in the new lunar exploration undertaking. On December 20, 1963, NASA Administrator James E. Webb announced the selection of the Boeing Company to build the Lunar Orbiter. After the Christmas holidays had delayed NASA-Boeing final contract talks, they began on January 6. The Office of Space Science and Applications sent Headquarters representatives and Langley officials to Seattle. The conference resulted in an agreement on basic task areas which NASA and Boeing would work out prior to actual contracting, and a tentative schedule of activities for the next 60 days. At the same time NASA people conferred with the U. S. Air Force Plant Representative at the Boeing Company and learned that greater support would be available due to the cancellation of USAF's Project Dyna-Soar. The NASA representatives left Seattle for the Jet Propulsion Laboratory at Pasadena, California. They spent a day making arrangements between JPL and NASA centers about the use of the Deep Space Network for Lunar Orbiter.

Following these West Coast preparations, NASA-Langley representatives met with Lockheed and Lewis Research Center people concerning the Agena and its integration with the spacecraft. Langley sent an intercenter agreement to Lewis to cover Agena-Lunar Orbiter interface.
The Lunar Orbiter Program Office in Washington conducted an information meeting to acquaint representatives of the various government mapping agencies with the Lunar Orbiter spacecraft design and the NASA mapping requirements as they existed at the time. By late January, Boeing officials at Langley completed the preliminaries to actual contract negotiations and gave a detailed presentation of all elements of their proposal with tentative cost estimates and funding requirements.

Lunar Orbiter preparations accelerated during February as NASA officials met again with Air Force people concerning the role which the Air Force Plant Representative was to play at Boeing. Following this meeting NASA's Office of Space Science and Applications drafted a document defining the nature of USAF support for Lunar Orbiter and sent it to Langley and USAF for approval. The Lunar Orbiter Program Office desired to make as much use as possible of Air Force technical support at Boeing, especially since the Air Force had extensive experience with Eastman Kodak's photographic system. Meanwhile Boeing representatives met at Langley with officials from the Lewis Research Center to discuss the problems of integrating the Agena and the spacecraft systems and the distribution of responsibilities involved in this task. Boeing and NASA officials agreed that Lewis would handle the shroud which would enclose the Lunar Orbiter atop the Atlas-Agena.

launch vehicle. Eventually Lockheed, the contractor for Lewis, had to subcontract the shroud and turned to Boeing for this. Boeing thus became Lockheed's subcontractor. Boeing would take care of the adapter and separation systems which would integrate the spacecraft-shroud combination with the Agena and separate them at the proper time in space. Other Boeing officials continued to work out cost estimates with Langley contracting officers, and Langley finished drafting an integrated work statement towards the end of the month. These preparations enabled NASA to begin detailed contract negotiations with Boeing, and talks commenced on March 2.²

While the Office of Space Science and Applications (OSSA), the Langley Research Center, and the Boeing Company proceeded to work out the fine points of the Lunar Orbiter contract, some Congressional criticism over NASA's choice of contractors rumbled down from Capitol Hill to NASA Headquarters. According to Aviation Week & Space Technology NASA decided to choose the Boeing proposal "because it offered the greatest assurance of mission success," and although the Seattle firm's price tag was seemingly the most expensive (approximately $60 million) "... the firm won the contract because of the high reliability factor in spacecraft design approach."³

As satisfying as this may have been to NASA and Boeing it struck a dissonant chord with Congressman Earl Wilson of Indiana who questioned NASA's selection of Boeing's costly proposal over that of the


Hughes Aircraft Company which would have cost supposedly half as much. The Space Science Subcommittee of the House Committee on Science and Astronautics, chaired by Congressman Joseph Karth of Minnesota, joined Wilson and questioned NASA spokesmen extensively about their choice of Boeing, but despite criticism NASA succeeded in convincing the Congress that "Boeing's proposal was selected because of its three-axis system rather than the spin-stabilized system suggested by Hughes."\(^4\) Although one approach was not decisively better than the other, the three-axis system greatly reduced the technical difficulties involved in the photographic system. This had been the determining factor in NASA-Langley evaluations of the five bidders' proposed payloads.

Having vaulted the Congressional hurdle NASA's Office of Space Science and Applications turned to face several problems within the agency which involved possible duplication of work and development. Earl D. Hilburn, Deputy Associate Administrator for Industry Affairs, notified Edgar M. Cortright in OSSA early in March that his office was concerned about the Lunar Orbiter Program Office's apparent intention to allow Boeing to develop a new attitude control system despite the fact that NASA had already invested $10 million in research and development for such systems for the Ranger and Mariner spacecraft. Hilburn pointed to the possibility that Boeing might desire to use the Lunar Orbiter contract as a means to justify building up a new tech-

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nological capability in attitude control systems in order to compete more successfully with more experienced firms which already possessed this capability. Hilburn requested that Cortright scrutinize any such situation in contract negotiations with Boeing and establish a reason for any seeming duplication of effort.\(^5\)

Cortright responded to Hilburn quickly with a lengthy description of the NASA-Boeing negotiations through March. The Lunar Orbiter Program, he stressed, was attempting to maximize the use of flight-proven hardware. This meant that Boeing would serve as the prime systems integrator because it alone retained the responsibility for the Lunar Orbiter spacecraft structure and its attitude control system. Boeing and NASA would spend more than 50% of the contract funds on hardware which Eastman Kodak and RCA would supply.

Contrary to Hilburn's major worry, the Boeing Company had a well developed electronics capability gained through its experience as contractor for the Bomarc and the Minuteman systems, and despite this NASA negotiators had encouraged Boeing to look for companies with greater competency in guidance systems: Northrop, Philco, General Electric, and Bendix for example. Moreover, during the final phase of the Ranger Program when another block of spacecraft had been under consideration, Northrop had conducted several very useful studies for NASA to determine what Ranger technology might have practical applications in future programs, and this information had proved a very sig-

\(^5\)Memorandum from Earl D. Hilburn, Deputy Associate Administrator for Industry Affairs, to Edgar M. Cortright, Deputy Associate Administrator for Space Science and Applications, March 19, 1964.
nificant input to Boeing. Indeed both the Lunar Orbiter Program Office and the Boeing Company were basing contract talks upon the axiom that they use as much off-the-shelf hardware as possible. 6

Cortright stressed also that because the attitude control system of the Lunar Orbiter spacecraft would have to fulfill many more demands than that of a Ranger or a Mariner deep space probe and because the system was so interrelated to all other spacecraft systems, the Office of Space Science and Applications had decided that the prime contractor, Boeing, should take the full responsibility for the attitude control system and its integration with all other systems. However, NASA and Boeing had reached agreement that the latter would use at least the following items of hardware in building the attitude control system:

1. Inertial Reference Unit - to be purchased from Kearfott - previously used on Mariner C.

2. Sun Sensor - to be purchased from Bendix - previously flight qualified.

3. Canopus Sensor - identical with the one onboard Mariner C - JPL fabricating this item - Boeing would request proposals from 7 contractors including Northrop, using JPL specifications.

4. Reaction Control System (thrusters, squibs, filters, regulators, etc.) - to be purchased from various companies - Boeing to construct the nitrogen tanks.

5. Flight Programmer - due to the complexity and the critical importance of this unit, Boeing would retain full responsibility but would purchase items for its construction from various companies as it deemed fit. 7

6 Memorandum from Edgar M. Cortright to Earl D. Hilburn, April 8, 1964.

7 Ibid., p. 2.
The brain for the Lunar Orbiter would be the Flight Programmer, an electronic wizard approximately the size of a shoe box, and its performance could determine the success or failure of any mission to the Moon. Because of the crucial role of the Flight Programmer, its configuration depended upon the design of the rest of the Lunar Orbiter's systems. Its completion would have to await the integration of the spacecraft's other vital components so that it could be placed in the spacecraft as the central nerve center linking all of the parts together into an electronic organism.

The Office of Space Science and Applications believed that Boeing had to retain the complete responsibility over the Programmer, the attitude control system, and their integration. Boeing also would conduct any necessary analyses, engineering, and computer studies of this system in order to have the working flexibility to cope with unforeseen problems and unexpected changes. This arrangement in no way meant that Boeing would undertake the completely new design and fabrication of a unique attitude control system. On the contrary the record demonstrated convincingly that the contractor was attempting to use as many off-the-shelf and flight-proven items of hardware as possible and that it was taking advantage of the experience gained by earlier NASA projects.

A more difficult problem impinging upon contract negotiations was the working relationship which Boeing and NASA were going to have with

8 Ibid.
the two major subcontractors: RCA and Eastman Kodak, especially the latter. Eastman Kodak's photographic system was to be the heart of the Lunar Orbiter, and this meant that Eastman Kodak would play a decisive part in the success of NASA's newest space venture. However, NASA and Boeing had to define and limit the extent of this firm's participation in the Lunar Orbiter Program.

One very real reason for this became apparent when Boeing suggested that the Lunar Orbiter Program use the Eastman Kodak facilities for reconstituting and processing photographic data from the spacecraft. Boeing considered this to be advantageous because of the presence of the NASA-owned Ground Reassembly Printer at the EK plant in Rochester, New York.\(^9\) Lt. Col. Clifton B. James, Assistant for Photography, USAF Office of Space Systems, raised the first sign of disapproval of the Boeing idea in a memorandum to Brockway McMillan, the Under Secretary of the Air Force, in February. He stressed that "the achievement of large scale lunar photography will most certainly create wide public interest which can be compared with the acclaim accorded to Sputnik I and the first manned orbital flight."\(^10\) Because of the great potential impact of such an event and because it would be sustained not by one but by five photographic missions, James felt that

\(^9\) Memorandum from Dr. Homer E. Newell, Associate Administrator for Space Science and Applications, to Dr. Robert Seamans, Associate Administrator of NASA, March 19, 1964.

United States space exploration would profit best if the National Aeronautics and Space Administration managed every facet of the processing, handling, and distribution of all photographic and other data transmitted to Earth by the spacecraft. James stressed that "the selection of a contractor's facility for establishing the Lunar Photographic Production Laboratory will not only detract from the potential prestige of this program, but it will also result in management problems. . . ."\textsuperscript{11}

In NASA Seamans read the James memorandum and sent it on to Homer E. Newell in OSSA for review. After evaluating the criticisms which James had raised Newell's office resolved that although "the consequences of performing this work at Eastman Kodak are uncertain, the possible disadvantages appear to outweigh the advantages.\textsuperscript{12} Newell felt that Eastman Kodak with its reputation for strong security consciousness might hinder the accessibility of interested parties to the lunar photographic data. Therefore, his office recommended that NASA conduct the processing of Lunar Orbiter photographic data, most likely at Langley, using technicians from EK in the initial stages of data reduction. All of this work would be done under NASA auspices and management. Boeing, establishing the more conventional cost-plus-fixed-fee contract relationship with the Eastman Kodak Company, would have to accept NASA's position as final.

\textsuperscript{11}Ibid., p. 3.

\textsuperscript{12}Newell, \textit{op. cit.}
With most anticipated problems successfully resolved, the Langley Research Center and the Boeing Company signed the Lunar Orbiter contract on April 16 and sent it to NASA Headquarters in Washington for final review and approval. In the interim Langley, Boeing, and OSSA people had spent two days at the beginning of the month in Florida at the Kennedy Space Center inspecting facilities for the Lunar Orbiter and briefing personnel there on Orbiter requirements which KSC would need to meet. Scherer noted that the program needed new hangar facilities at Cape Kennedy if it wanted to avoid an undue burden on existing space. Subsequent to the signing of the contract Langley sent a preliminary Project Development Plan to Headquarters but made clear that it still had to work out agreements with the Jet Propulsion Laboratory and the Lewis Research Center concerning their specific roles in the program.13

JPL was facing manpower shortages in the Ranger and Surveyor Programs and thus registered some resistance to the proposed extent of its participation in the Lunar Orbiter Program. By mid-April Langley was experiencing difficulties in defining exactly what tasks JPL would perform for the program, but this was not the fault of JPL. Langley had requested that JPL make a definitive study of Lunar Orbiter tracking data requirements to parallel a similar one which Boeing was conducting. At the Lunar Orbiter Mission and Trajectory Analysis Meeting on April 15, JPL people had met the Langley request by proposing to train a Boeing engineer at their facilities for three months and then let him perform the study. When Langley had asked that JPL set up the operational

computer programs for Lunar Orbiter, the Pasadena-based NASA contractor suggested that Boeing erect its own computer facility to simulate the Space Flight Operations Facility, accomplish its own programming, and check out and integrate this set-up into that of JPL at the SPOF.

The Jet Propulsion Laboratory maintained a conservative position in order to avoid any direct responsibilities for the Lunar Orbiter trajectory design analysis. It desired to serve as consultant and educator of Boeing personnel, but it did not want to commit itself to responsibilities which could cause schedule lags and put Langley in an embarrassing position with Boeing. JPL also desired to avoid becoming the major center for lunar and deep space trajectory design and mission analysis as long as these needs could be fulfilled by other organizations in the aerospace industry and the U. S. Government. 14

The situation with JPL support dragged on through a series of prolonged meetings and negotiations in July, but at the same time events continued to move ever more rapidly toward the conclusion of a successful contract. Early in May the Program Manager, Scherer, pointed out that the total period of NASA-Boeing contract negotiations had been remarkably short due to the clarity of the Request for Proposal and the very good response which Boeing had made. Moreover, both NASA and the Boeing Company had worked out an excellent implementation cycle for program activities while, simultaneously, Boeing had supplied Lang-

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ley and NASA Headquarters with very extensive supporting documentation which detailed, among other things, the cost backup data from the major subcontractors.

Scherer ascribed Boeing's excellent responsiveness during the period of negotiations to the fact that NASA had predetermined the incentive features of the contract in the RFP and to the absence of a letter contract which created a sense of urgency in the contractor to complete negotiations as soon as possible. All of Boeing's efforts and its willingness to listen to and analyse NASA's requests paid off on May 7, 1964, when James E. Webb signed the document approving the Lunar Orbiter contract and making the program an official NASA commitment.

The Lunar Orbiter contract was a new step for the National Aeronautics and Space Administration in several significant ways. First, brief but thorough and intensive negotiations had produced the contract. It was based upon well defined and clearly understood requirements as described in the Request for Proposal. Secondly, the incentive type of contract represented a new attempt by NASA to form a firmer though more flexible bond with the contractor and the subcontractors. It was the first step for Boeing and for the Langley Research Center into the realm of lunar and deep space probes. Moreover, it constituted the basis for a major new program in the U. S. exploration of the Moon and as such would require the close correla-

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tion of activities and the precise interaction between three NASA centers and Headquarters in addition to the contractors. Unlike the Ranger Program conducted in-house by the Jet Propulsion Laboratory, NASA had diffused the tasks in the Lunar Orbiter Program, and the Langley Research Center was serving as the master coordinator of far-flung activities between the east and the west coasts of the United States. The program's major objectives, the acquisition of scientific data about the Moon and its environment, and the implementation at the earliest possible date of simple, reliable engineering measurements to determine the soundness of the spacecraft's design, would provide vital information for the Apollo manned lunar landing program.16

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Seven months of process definition, bidding, and contracting culminated in NASA's first new lunar exploration program since the initiation of Ranger and Surveyor. This event was hardly noticed in the turbulent atmosphere in which the U. S. space program existed at home and abroad. The Congress busily raked NASA and JPL over the coals for poor management in the Ranger Program, while the first manned Gemini flight, scheduled for launch late in 1964, was experiencing setbacks. Everywhere, it seemed, the critics of America's space exploration efforts were leveling their verbal artillery at NASA. They pointed to Soviet manned and unmanned space accomplishments and asked why the United States allowed six consecutive Ranger missions to fail. Under these circumstances, the fledgling Lunar Orbiter Program got off to a very promising if inauspicious start.

Four different aspects of the new program became vitally important during the twelve months following the signing of the contract: (1) funding, (2) spacecraft design, fabrication, testing, and integration with the launch vehicle, (3) mission design, and (4) the establishment of schedules and interfaces between the various NASA centers and the contractors. Funding problems became more complex once the definitive contract had been approved and constituted one of the dominant constraints defining the flow of activities during the entire course of Lunar Orbiter operations. A brief description of funding through the end of 1964 will illustrate the problem.
Beginning in February 1964 the Office of Space Science and Applications had decided to commit to Lunar Orbiter the full $20 million which Congress had appropriated for FY 1964 specifically for an orbiter. However, the negotiated contract of May 7 obligated NASA to provide Boeing with funds as it desired them, if the contractor were to be held to the incentive provisions in the contract. This meant that NASA had to establish and maintain a minimum funding rate to avoid schedule lags. Although NASA committed the FY 1964 funds, the Lunar Orbiter Program Office faced a new situation in FY 1965, beginning July 1, 1964. During the contract talks Boeing had predicted an expenditure rate of $26.1 million for that fiscal year, but by May this sum had increased to $37.1 million.¹ A detailed PERT (Performance Evaluation Review Technique) revealed one reason for this sudden rise. It found that by compressing the development phase of the program NASA could gain more time for the testing phase. Acceleration of development, however, would require a higher funding rate than Lunar Orbiter Program officials had originally anticipated.

Realizing this, the Office of Space Science and Applications released a guideline of $31.5 million for FY 1965 to the Langley Research Center in the spring of 1964, $28.9 million to be spent by Boeing. These two figures were considerably less than the $39.7 million which Langley had requested, of which Boeing was to expend $37.1

¹Memorandum, Subject: Lunar Orbiter Funding, POP - 64-3, August 24, 1964.
million. But OSSA preferred to remain conservative for the time being because it wanted to wait until Boeing could supply more accurate, concrete information before making a decision to increase the funding rate. Oran W. Nicks, Director of Lunar and Planetary Programs within OSSA, felt that the Lunar Orbiter funding requirements could increase at an uncomfortably fast pace, and, thus, compromise other projects within OSSA. In August he brought this problem up with Floyd L. Thompson, Langley Director, and requested him to review the funding situation and its potential impact upon other programs.² By late August, several other uncertainties troubled the financial horizon of Lunar Orbiter. The rate of expenditure at Boeing remained the foremost headache of NASA planners because Boeing had not yet finished contract negotiations with its two major subcontractors: Eastman Kodak and RCA.

The scope of the funding problem revealed the need for closer cooperation between Langley and NASA Headquarters. Both organizations sent representatives to an August 19 meeting at Langley to examine and resolve their differences and strengthen the coordination of policies pertaining to Lunar Orbiter.³ At the meeting officials from the various Langley offices connected with Lunar Orbiter operations gave detailed presentations of their work and requested further support or clarification of policies pertaining to the program.

²Memorandum from Oran W. Nicks, OSSA, to Floyd L. Thompson, Director of the Langley Research Center, August 20, 1964.

³Minutes of Lunar Orbiter Program Funding Meeting, Langley Research Center, August 19, 1964.
Headquarters people made clear that they wished to establish much firmer ties with Langley to ensure a better request-response relationship throughout the program. Langley people expressed concern that they had had to make decisions without the help of such useful tools as complete monthly funding reports from Headquarters which they could use to gauge their expenditure flow.

Another pressing matter centered on Langley's desire to fund Boeing three months in advance. This would allow enough flexibility to keep hardware procurement from falling behind schedule. But, due to the acceleration of development during the tight money situation in FY 1965, Langley's request appeared to be out of the question. Already the funding to Boeing tended toward a minimum below which it could not go without precipitating serious schedule changes. Langley and Headquarters officials decided to establish a minimum level for total expenditures at $41 million for fiscal 1965. Cost reduction appeared unlikely in every program area except Air Force support services. Here, according to Nicks, the very high projected figure of $2.45 million for FY 1965, which Langley's August Program Operating Plan had forecast, might be subject to reduction.

In FY 1964, USAF had charged NASA an expensive 6% of Langley's combined contract costs as the fee for its support. NASA wanted the more reasonable rate of 1½ to 2% which it had received from the Navy and the Army for their various support services. Nicks maintained that if NASA could obtain a figure of 1.5% of the Lunar Orbiter con-

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Ibid.
tract costs for FY 1965 as the rate of charge for USAF support, then it could alleviate some of the financial pressure which limited the flexibility of Lunar Orbiter funding in the coming fiscal year.\(^5\)

This "if" would have to be worked out with the Air Force. Meanwhile the participants in the August 19 funding meeting agreed that no contract changes would be made if they would increase funding above the FY 1965 guidelines or above those laid down in the Project Approval Document or above the total program guidelines unless the Lunar Orbiter Program Office in Washington had subjected such proposed changes to the most thorough scrutiny.\(^6\)

The Lunar Orbiter funding situation was further clouded by the fact that the bulk of the procurement and development expenditures would come during fiscal 1965. This pessimistic reality placed a strict constraint on administering the incentive contract with Boeing; it prompted Langley Director Floyd L. Thompson to comment that "if we aren't prepared to play table stakes, we shouldn't be in the incentive poker game."\(^7\) To this Captain Scherer added that "when the government asks a contractor to assume the risk of an incentive contract, it must assume itself the responsibility for funding the contractor as he needs it."\(^8\) He named the figure of $41.8 mil-

\(^5\)Memorandum from Oran W. Nicks, Director of Lunar and Planetary Programs, to the Director of Program Review and Resources Management, August 21, 1964.


\(^7\)Memorandum from Lee R. Scherer to Oran W. Nicks concerning Lunar Orbiter FY 1966 Funding, September 4, 1964, p. 2.

\(^8\)Ibid.
lion as the rock-bottom minimum for the program in FY 1965 and stressed that any slip below this would cause schedules to lag and force basic alterations in the contract.

Lunar Orbiter funding became very tight in September at the time when Boeing was completing its contracts with Eastman Kodak and RCA at estimated costs somewhat higher than originally projected. NASA Headquarters remained steadfast in its retention of the $41.8 million FY 1965 funding minimum although Langley had called for $45.9 million. This allowed no margin for underestimation of costs or compensation for unforeseen development problems.

Everyone involved in the program realized what Scherer formally stated in a memorandum to Nicks. To allow the program to fall behind schedule because of too stringent funding would be tantamount to erasing the advantages of the incentive contract. If NASA induced the contractor to lose confidence in the contract because of a necessity to renegotiate all or part of it due to NASA niggardliness, then the overall success of the program would be jeopardized. In view of the setbacks in JPL's Ranger Program NASA could ill afford a major crisis in its newest attempt to obtain lunar photography for scientific and manned space flight applications.

The growing seriousness of this problem brought NASA Headquarters and Langley officials together on September 9. They established a new funding level based upon the increased requirements of Lunar Orbiter.

9 Ibid.
This raised the original $94.6 million figure for the FY 1965-FY 1966 period to $105 million. The new ceiling brought greater flexibility to Langley operations and reassured the Lunar Orbiter Program Office in Washington that the incentive provisions of the Boeing contract would be maintained. Both Langley and NASA Headquarters concurred in the policy of holding all contract and schedule changes to the barest minimum.

Moreover, both undertook studies of their operations to determine where costs might be reduced, and by the end of 1964 Lunar Orbiter Program Manager Scherer had succeeded in pinpointing several ways to save more money. He passed his findings on to Clifford Nelson, Director of the Langley Lunar Orbiter Project Office, in a memorandum at the end of December. To avoid giving Boeing an excuse to increase costs, as contractors were wont to do when changes were made, Scherer emphatically requested that no changes be made if they would not contribute directly to the program's success. Nelson agreed with this policy, and it became the touchstone for NASA-Boeing relations during the course of the program.

Scherer further stipulated that his office would strengthen the policy for approving a change and that as far as possible all changes would be worked out between NASA and Boeing before they were approved. Only after this step had been taken would a change be negotiated. More-

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10 Memorandum from Homer Newell to Floyd L. Thompson, Subject: Guidelines for Lunar Orbiter Project, October 22, 1964.

over, Headquarters would tightly control the policy of making and implementing changes and would insist that the centers did the same.\textsuperscript{12} Scherer's instructions thus capped the funding talks which had taken place periodically during 1964, making all members of the Lunar Orbiter team very cost conscious. The talks greatly improved the administration of NASA's first major incentive-fee contract and fostered a keen awareness of the implications and potential pitfalls within the Lunar Orbiter contract among Boeing and NASA management. Indeed very little about the agreement remained to be seen, and this fact strengthened the cooperative relationship between NASA and Boeing by dispelling any illusions of either party about the work which had to be done.

Besides the strictest limitations on changes, Lunar Orbiter could be spared undue expenses in another specific area, according to Scherer: the planned need for redundant spacecraft to back up each flight spacecraft in the event of a failure before launch. Original plans had called for such redundant spacecraft, but after extensive consideration the Program Office concluded that direct substitution of one spacecraft for another between two launch windows, should the first one fail, was highly unlikely since the failure of one would necessitate an investigation of the other.\textsuperscript{13} Adding to this high improbability were the storage problems at Cape Kennedy and the necessity of maintaining the back-up

\textsuperscript{12} Ibid.

\textsuperscript{13} Ibid., pp. 2-3.
mission-ready condition while preparing the flight Lunar Orbiter for launch. Indeed the whole philosophy of spacecraft substitution was questionable, especially in a situation where every dollar counted. Scherer pointed out to Nelson that the earlier Pioneer and Surveyor Programs had originally made provisions for back-up spacecraft but later eliminated them. The Lunar Orbiter Program, by doing the same, could save a substantial sum of money.\textsuperscript{14}

This was not the only area where savings could be made. The spacecraft delivery schedule proved to be another item for cost reduction. The spacecraft were scheduled to arrive at the Cape Kennedy facilities more frequently than they could be launched and would become a bottleneck in the limited storage space there. Spacecraft \#8 would arrive a full six months before its launch date; this would demand that a "babysitter" keep it company for that length of time, clogging vital test and storage facilities. Scherer maintained that if changes were made in the delivery dates of the fifth through the eighth Lunar Orbiter, the storage vans and the test teams would be reduced and money diverted for use elsewhere.\textsuperscript{15}

Finally Scherer described to Nelson the possibility of reducing costs by economizing on redundant recording equipment which the Lunar

\textsuperscript{14}Ibid., p. 3.

\textsuperscript{15}Ibid.
Orbiter Program would employ at each site of the Deep Space Network to record incoming data from the spacecraft. Comparing the data acquisition requirements of the Mariner Program to those of Lunar Orbiter, Scherer pointed out that Mariner had only two recording equipments per site, one of which served as a back-up. The Lunar Orbiter Program planned to have three or more, which Scherer believed to be wasteful redundancy. He asked Nelson to review the need for so much recording equipment and to cut down on it wherever possible.16

By the end of 1964 Scherer's office in Washington and Nelson's at Langley had exposed and carefully analysed such incipient waste as redundant recording equipment, spacecraft delivery schedules, redundant Orbiters, Air Force field support, and contract and schedule changes.

The Lunar Orbiter

Program's top management successfully controlled problems which could later have tied up valuable time. NASA and the contractors hammered out problems in open meetings before they snowballed into nightmares. If funding difficulties for FY 1965 placed a major constraint on initial program operations, they also enhanced the performance of each task force engaged in the Lunar Orbiter Program, and the process of overcoming them thoroughly educated both NASA/OSSA management and Boeing officials about the increasing complexity of the whole undertaking.

16 Ibid., pp. 3-4.
CHAPTER VI

THE ANATOMY OF LUNAR ORBITER

It is now necessary to survey the development phase of the Lunar Orbiter Program and to describe briefly the problems encountered and the solutions found for them. A general description of the spacecraft will provide the reader a reference to use when following the course of events during the development phase. As finally designed Lunar Orbiter weighed approximately 850 pounds, was five and one half feet tall and five feet in diameter at its base, excluding the solar panels and the antennas. Structurally the spacecraft was made up of two decks supported by trusses and an arch. On the larger lower deck the main equipment was mounted: batteries, transponder, flight programmer, photographic system, inertial reference unit (IRU), Canopus star tracker, command decoder, multiplexer encoder, and the travelling wave amplification tube (TWTA), together with lesser units. Four solar panels and two antennas extended from the perimeter of the deck. On the smaller upper deck the velocity control engine (a rocket motor), the heat shield, fuel tanks, and the attitude control thrusters were located. In addition this deck held the oxidizer tank for the velocity control engine, the coarse Sun sensor, and the micrometeoroid detectors. The whole upper deck comprised a unit built around the velocity control engine and was detachable for test purposes. Directly under the engine was the high-pressure nitrogen tank which provided the pressure necessary to feed fuel to the velocity
control engine and the attitude control thrusters. This tank was one of the critical units; if anything caused it to lose pressure, the entire mission could be ruined.

These items of spacecraft equipment would mean little without the systems which performed the Lunar Orbiter mission. The Eastman Kodak photographic system has previously been described. Electrical power was derived from the power system which used two modes to acquire and generate electrical energy: (1) solar panels which converted solar radiation into an electric current, and (2) batteries which powered the spacecraft systems for short periods of occultation from the Sun. In periods when the solar panels would receive radiation from the Sun the power supply would run from the panels to the output voltage regulator to the other spacecraft systems (mode 1). This happened for the major part of the mission. At the same time solar radiation picked up by the panels would also be directed into the battery charge controller and from there a charging current would flow into the batteries as they could accept it. When no sunlight fell on the panels, the batteries would supply power to the output voltage regulator, and this would direct its flow to the spacecraft systems (mode 2). In addition the power system had regulators and controllers to reduce unusual fluctuations to a minimum and enough solar cells

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1 The Lunar Orbiter, prepared for the National Aeronautics and Space Administration, Langley Research Center, by the Space Division of the Boeing Company, Seattle Washington, revised April 1966, pp. 20-21.

2 See Chapter III, p. 45.

to allow micrometeoroid damage to some without dangerous reduction in the capacity of the solar panels.

Lunar Orbiter's position in space in reference to the Sun, the star Canopus, and the Moon was controlled by the attitude control system. This very vital part of the spacecraft was composed of Sun sensors, the Canopus sensor, and the inertial reference unit. While the IRU locked on to the reference points, the sensors supplied information to the flight electronics control assembly (FECA) and the flight programmer. These two units, in turn, controlled the spacecraft's attitude around its X (roll), Y (yaw), and Z (pitch) axes by activating the attitude thrusters. They also governed the orientation of the photographic system in relation to the surface of the Moon. Commands from Earth would make the spacecraft rotate a precise distance around each axis, and the rate of outputs of the gyros in the IRU would tell the flight programmer when the new attitude had been achieved. The IRU would then lock on again and maintain the spacecraft in this position relative to its three reference points.

After Atlas-Agena rockets launched the five planned Lunar Orbiters into either a parking orbit above the planet or a direct ascent trajectory to the Moon, there remained the task of changing the spacecraft's initial trajectory to carry it into the gravitational field of the Moon and then to deboost it into a lunar orbit. The velocity-control system held the responsibility for this task and had to ac-

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complish any changes in trajectory and speed. The heart of the system was a 100-pound-thrust rocket whose hypergolic fuel and oxidizer ignited when a command from the flight programmer opened the intake valves. A burn to change the spacecraft's velocity would then occur and continue until the valves closed. Duration of any burn would be determined by information from the accelerometer compared to prestored data in the flight programmer and direction of the engine's thrust would be determined by the attitude control system.

A nominal mission would provide for two midcourse maneuvers to bring the Orbiter's trajectory precisely in line with the point where the Moon would be when the spacecraft reached its gravitational field. From this predetermined point the Orbiter's velocity-control system would deboost the spacecraft into its initial orbit around the Moon. At this time NASA engineers and scientists would check out the systems before making any decision to transfer it to another orbit. Once they found the spacecraft's systems operating nominally, they would make a decision to inject it into a photographic orbit. The velocity-control rocket motor could be gimbaled and its thrust regulated, thereby greatly increasing the flexibility of Lunar Orbiter as a captive satellite of the Moon.5

Receiving and transmitting data to and from the spacecraft was the job of the communications system, an extremely complex assembly of components which could operate in four modes: (1) tracking and

5 Ibid., p. 29.
ranging, (2) command, (3) low power, and (4) high power. The communications system could send and receive data simultaneously while also providing velocity and ranging signals for the Deep Space Network's tracking system. The spacecraft's low-gain antenna picked up all incoming signals from the NASA-JPL Deep Space Instrumentation Facility (DSIF). Commands from DSIF were routed to the command decoder and stored. The spacecraft would transmit a command from Earth back to Earth for verification before ground controllers sent an execute command to the spacecraft. Upon receiving an execute command the communications system would advance the stored command from the decoder to the flight programmer to be carried out. Photographic, along with performance, environmental, and telemetry data, would be encoded, multiplexed, and transmitted to Earth by using the high-power mode.  

The temperature control system protected all of Lunar Orbiter's systems from the extreme temperature variations of the deep space environment. Heat from the Sun beating down upon the spacecraft could reach +250°F while areas not exposed to solar radiation would be subject to freezing cold up to -460°F. Tests of the Lunar Orbiter's systems revealed that some components could not withstand the prolonged hostile environment of space without sustaining crippling damage. The solution was a temperature control system, consisting primarily of materials which would hold the internal spacecraft temperature within the range from 35°F to 85°F. Beginning at the upper deck a heat shield

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6 Ibid., pp. 30-31.
insulated the spacecraft from heat and cold while the entire area down to the lower deck was enshrouded in a thin-skinned aluminized mylar and dacron thermal blanket which covered all equipment except the Canopus star-tracker's lens and the camera thermal door. The bottom of the lower deck was coated with a substance which had a high heat emission-absorption ratio. Small electric heaters could raise the internal temperature when it fell below 35° F. Thus the whole spacecraft was protected from the extreme temperatures of deep space and from erratic variations in temperature which could seriously affect performance. 7

Although much of the hardware in the spacecraft was "off-the-shelf," the integration of all of the ship's systems did not prove easy. Nor was the program free of difficult decisions involving trade-offs or crises concerning critical items in the various systems. The Lunar Orbiter Program was building a mission-unique, long-life spacecraft through a major contractor who had never manufactured a deep space probe before and who was operating under an incentive-fee contract.

NASA on the other hand attempted to apply the lessons it had learned from the Ranger and Surveyor experiences at JPL, and top management in the Office of Space Science and Applications had decided to enlarge the base for conducting unmanned lunar exploration programs to include the talents of the Langley Research Center which never had

7 Ibid., pp. 32-33
directed a major NASA space flight program. Both NASA and Boeing had agreed on a singleness of purpose, a unity of operation, and a set of basic objectives early in the Lunar Orbiter Program, and these three factors remained intact throughout its operation. Finally, NASA wanted Boeing to meet its schedules, but it impressed upon the prime contractor that it was in no hurry for a failure. This philosophy went far to secure five major space achievements for the United States in 1966 and 1967.

One of the first hardware items to cause the two organizations concern was the velocity control engine. The Boeing Company had proposed using the same Marquardt engine which the Apollo Program was employing. But during preliminary testing for Apollo requirements the rocket developed problems which caused Lunar Orbiter officials to have second thoughts, and on April 21, 1964, Captain Scherer visited Marquardt with members of his staff to determine the seriousness of the situation. He and his group found that Apollo mission-peculiar requirements were the primary cause of the troubles and that this would not affect the use of the engine in Lunar Orbiter. However, Scherer recommended that until the Marquardt engine proved reliable for Apollo such alternatives as the JPL Surveyor vernier engine should be studied.8

While the Marquardt rocket motor was not so critical to the pro-

gram's mission, the velocity-over-height sensor (V/H sensor) was. It could not be replaced easily by another component of a different kind, and its function was critical to the performance of the photographic system. The limitations of the V/H sensor's versatility also set the parameters of any Lunar Orbiter photographic mission. It was required to determine precisely the image-motion compensation factor for photography below 950 kilometers altitude where the spacecraft's velocity relative to the Moon's surface would affect the degree of resolution of all photography. The V/H sensor had a dynamic range of 4 to 1, and at 950 kilometers the image-motion compensation could be deleted without significantly affecting the quality of resolution in photographs. High resolution pictures might be reduced in their accuracy from 20 to 23 meters, but the case would be altogether different in an elliptical orbit which brought Lunar Orbiter as low as 46 kilometers above the Moon's surface. At this altitude the V/H sensor would have to compensate for image motion to avoid "smearing" in a photographic exposure. Since the V/H sensor had a dynamic range of 4 to 1, it could theoretically compensate for image motion up to an altitude of 184 kilometers. But beyond this, until the spacecraft reached 950 kilometers, "smearing" would definitely affect resolution unless some alterations were made in the system. This placed a major constraint on Eastman Kodak's photographic system.  

The second constraint on Lunar Orbiter photography was the disparity between the actual rate of picture-taking and the speed of the processor. Plans called for Orbiter to expose 20 frames on a single pass over any one target. After the photo system had taken the pictures and processed them, the film would bypass the readout system and be stored. When ground controllers wanted the data from the last X-number of pictures to be processed, they had to command the film to be read out, and this called for a readout looper in the system. The size of this looper limited the number of pictures to 20 frames which could "be moved" back at any one time for readout.10

Finally the rate and number of commands which the camera system could accept placed a further constraint on the frequency of exposure for single shots and bursts of shots. The photographic system could operate in a contiguous coverage mode and a site-search mode. In the first mode if the maximum frame capacity of the readout looper were coupled with a picture-taking rate of one every 2.5 seconds, then a total square 85 x 85 kilometers could be covered before reaching the looper's limit. This mode would be applied in locating a landed Surveyor, and it actually had far better specifications than those which the Request for Proposal had stipulated. Lunar Orbiter would use the second mode in screening areas for potential Surveyor landing sites, and it could set a picture burst of 14 at a rate of one every 10 seconds. This would cover an area of 200 x 200 kilometers. At four

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10 Ibid.
times the altitude required to do this, a burst of 20 pictures at 10 second intervals could cover a square of 350 x 350 kilometers in which contiguous coverage would approximate 4 meters.11

Because the photographic system being built by Eastman Kodak became the pacing item in the development and testing phases of the program, the Program Manager's office constantly had to monitor the EK operation and Boeing's contract relationship with the Rochester, New York, firm. As time passed, the technical difficulties involved in perfecting the EK photographic system proved less restrictive to a smooth interface with Boeing's total operation than did the contract relationship between the two companies. Although Boeing was working under the provisions of an incentive-fee contract, EK had insisted upon a more conventional cost-plus-fixed-fee contract, providing no overwhelming motivation to beat or even meet schedule deadlines.

Boeing on the other hand was very highly motivated to make the program a total success, but it had subcontracted with Eastman Kodak because of that company's special technological capabilities. Boeing had little, if any, alternative to EK, but it made the mistake of establishing a somewhat loose contract relationship with EK while Boeing itself was operating under a more thoroughly worked out arrangement with NASA. As a result both Boeing and NASA experienced trouble which might have been avoided under a different kind of contract agreement or at least under a more strictly controlled cost-plus-fixed-fee contract with the Eastman Kodak Company.

11Tbid., p. 2.
Two other problem areas became evident by September 1964 when Boeing commenced tests on the thermal model of Lunar Orbiter. The first was an overload on the power system because of increased need for electricity during periods when the spacecraft could not use its solar panels. The Inertial Reference Unit placed the greatest demand on the power system, and tests revealed that a battery with a greater capacity was probably needed to meet the demand. Boeing and NASA engineers also examined the possibility of changing the orbit design to give the spacecraft more sunlight instead of having to use a heavier battery. During the Lunar Orbiter Program's First Quarterly Review at the Langley Research Center Captain Scherer pointed out that "if the initial orbit of Lunar Orbiter is made elliptical with a higher apolune, the day to night ratio would be improved and could be used to solve the problem." In the final resolution of this problem the orbit design was changed without greatly affecting photography, averting the necessity for a heavier battery.

The second problem concerned the spacecraft's fuel and oxidizer tanks which Boeing was purchasing from the Bell Aero Systems Company. As off-the-shelf hardware developed for the Apollo Program, the tanks had failed to pass qualification tests because of repeated rupturing of their bladders. The Lunar Orbiter Program required extra qualification tests of the tanks, but this would triple their cost. So

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possible alternatives were investigated. 13

All known problem areas which had come to light since NASA Admin-
istrator James E. Webb had officially approved the Boeing Lunar Orbiter
contract were aired at the First Quarterly Review held on August 26
and 27 at the Langley Research Center. Boeing summarized its opera-
tions for top NASA Headquarters and Langley management officials on
the first day and then devoted the second day to detailed presentations
on specific areas of the program to NASA personnel directly working
in each area. The Lunar Orbiter Program Office rated
the total presentation very good, but noted that Boeing had treated
its relationship with the Eastman Kodak Company and RCA super-
officially. No representatives from EK or RCA were present at the
Langley review, and officials from the Office of Space Science and Ap-
lications felt that a Boeing-Eastman Kodak-RCA team presentation at
subsequent reviews would be very desirable. 14

During the course of the review NASA and Boeing people treated
the technical problem areas very thoroughly and discussed other dif-
ficulties related to spacecraft design and engineering. Boeing showed
three more areas where work was required to attain the maximum func-
tional efficiency in the configuration of the spacecraft. The first
was spacecraft weight, a factor limited by the lifting capability of
the Atlas-Agena launch vehicle. Boeing was aiming for an 800-pound
spacecraft weight after separation from the Agena and before any mid-

13 Ibid.

course maneuver. Originally the preliminary Lunar Orbiter design had envisioned an 860-pound spacecraft, but two major steps had successfully reduced this figure. First Boeing and NASA had decided to use integrated logic circuits in the Control Assembly Electronics since this would save 14 pounds compared to the use of discrete parts. Secondly, the need to use additional one-pound thrusters in the attitude control system was eliminated when engineers gimbaled the half-pound thrusters to work in coordination with the Velocity Control Engine. This further eliminated plumbing and reduced the quantity of attitude control gas. The addition of gimbals, actuators, and bearings added weight, but still 7 pounds were saved.

Lunar Orbiter's overall weight at the time of the Langley review/approximately 842 pounds. Further study and engineering changed this weight figure during the course of the program. 15

Review of the power system difficulties and subsequent findings showed that under the planned night flying conditions the Orbiter's 12 ampere-hour battery would require an excessive charging rate, approximately 4.5 amperes, to meet the power needs of the other spacecraft systems. This high rate could cause battery failure, and Boeing engineers had worked out three possible solutions: (1) install a heavier, higher capacity battery, (2) turn off some equipment during the night periods, and (3) increase the time of the spacecraft's exposure to the Sun by altering the orbital parameters to be approximately 1850 kilometers at aposelene and 46 kilometers at periselene. This last alternative would affect the spacecraft's photographic capa-

15Ibid., p. 3.
bilities because the increased period of orbit would necessitate a
decrease in the spacecraft's orbital inclination to the Moon's equa-
tor. However, NASA and Boeing agreed that it would be easier to
work out a final solution for the power system based upon the third
choice than to implement either of the first two alternatives.

The Langley review also tackled the dilemma of the Marquardt en-
gine, specifically the weight of the engine's propellant versus the
transit time from the Earth to the Moon and the impulse required to
make the transit and the injection into lunar orbit. If the spacecraft
was to achieve an initial elliptical orbit of 925 by 46 kilometers, it
required a total velocity change of slightly less than 3,600 feet per
second. This meant that an Orbiter weighing about 810 pounds at sep-
oration from the launch vehicle would require a specific impulse of
290 seconds to accomplish transit. The Marquardt engine, which had
yet to qualify for the Apollo mission, might not be capable of gener-
ating an impulse of this duration. Engineers in the Lunar Orbiter Pro-
gram and Project Offices began studying the possibility of decreasing
the total impulse and altering the spacecraft's trajectory to
place it in a more convenient initial elliptical orbit prior to trans-
fer to the final orbit.17

After reviewing the Marquardt engine, the Langley-
NASA Headquarters Lunar Orbiter staffs took up the examination of the
last major problem to be considered at the First Quarterly Review. This

16 Ibid., p. 4.
17 Ibid.
was the ability of the photographic system to withstand the intense vibrations of the launch. The Eastman Kodak Company claimed that the vibration test levels were too high and that flight data on the launch vehicle did not warrant the high levels which Boeing had stipulated in its Environmental Criteria document. Boeing and the Langley Lunar Orbiter Project Office decided to reexamine the flight data of the Atlas-Agena launch vehicle before reaching a decision on Eastman Kodak's complaint. With this problem exposed, the First Quarterly Review ended its intensive two-day evaluation of the program's major technical problem areas. Two months later another review revealed still more technical and engineering dilemmas.
Lunar Orbiter was designed not only to perform photography but also to carry three scientific experiments not directly related to the photographic mission. A summary discussion of these experiments should help explain the direction of program thinking on non-photographic scientific investigations of the lunar environment and show how the experiments presented interface problems with the total configuration of the spacecraft. Originally, the JPL Surveyor Orbiter concept envisioned a spacecraft packed with various experiments to gather a wide range of data on the Moon and its environment. Weight limitations and the lack of a reliable launch vehicle had torpedoed this large-scale approach to an orbiter in 1963. With the birth of the Agena-class Lunar Orbiter there was a retrenching of thought on the number and types of scientific experiments which the spacecraft could accommodate on a long-life mission around the Moon. While the Office of Space Science and Applications worked out the Request for Proposal for a new orbiter, one of its committees was evaluating the kinds of experiments which would be most useful to immediate NASA objectives as well as to scientific investigation of the Moon. The major work in this area had fallen to the Planetology Subcommittee of the Space Science Steering Committee of NASA.¹

¹See the Minutes of the Planetology Subcommittee of the Space Science Steering Committee in the NASA Historical Office Lunar Orbiter Preliminary History files. The meetings of the subcommittee were conducted periodically during the entire course of the Lunar Orbiter Program.
The Planetology Subcommittee narrowed down the field of experiments to be included on Lunar Orbiter early in the program's history. It found that one almost indispensable scientific experiment which the spacecraft would carry was a device for recording selenodetic data of the Moon. Gordon MacDonald of the University of California at Los Angeles, a member of the subcommittee, explained at a meeting with Lunar Orbiter officials on September 24, 1963, why such a device was needed. He stated that if the spacecraft was to be flown in a low elliptical orbit around the Moon, it would be mandatory on the first Orbiter mission to track the spacecraft and determine by accurate measurements its behavior in orbit. A selenodesy experiment which could record data for a period of at least 60 days at an altitude of 160

2 MacDonald's words understated the significance of the selenodetic data which the five Lunar Orbiters eventually gathered. The discoveries made of the Moon's gravitational field by the selenodetic experiments onboard the five spacecraft, especially Orbiter V, dramatically revealed the existence of large mass concentrations under the ringed maria on the nearside of the Moon. Data on the orbital behavior of the five spacecraft enabled NASA scientists to construct a gravimetric map of the Moon's nearside in 1968, and the discovery of "mascons" by scientists at the Jet Propulsion Laboratory confirmed the presence of gravitational anomalies for both the Lunar Orbiter Program officials and those in the Apollo manned lunar landing program. The fact that irregular gravitational attraction caused the Lunar Orbiters to accelerate during certain periods of their orbits and that the resulting distortion of the orbits presented a major phenomenon in tracking has more than justified the presence of the selenodetic experiments onboard the Orbiters. Moreover, the "mascon" discoveries convinced Apollo Program management to redesign the Apollo VIII mission and to plan an orbital mission for Apollo X rather than a landing, so that more precise tracking data could be gained prior to actually landing men on the Moon. For a precise summary of the "mascon" phenomenon, see "Mascons: Lunar Mass Concentrations," by P. M. Muller and W. L. Sjogren of the Jet Propulsion Laboratory in: Science, Vol. 161, No. 3842, August 16, 1968, pp. 680-684, and refer to the annotated bibliography in this study.
miles above the Moon on the first mission could sufficiently confirm the safety of putting subsequent Orbiters into orbits which would go as low as 20 miles above the Moon. Moreover, the selenodetic data gained in a 60 day period would be invaluable for the first Apollo lunar mission.³

The Lunar Sciences Subcommittee's Working Group on Selenodesy had developed information on lunar gravity and mass since its inception on May 4, 1962.⁴ Originally the Group had provided major technical guidance for the now defunct Surveyor Orbiter Project, and it made a valuable contribution to Lunar Orbiter mission planning as a result of this experience. The Group's chief concern was the design of the trajectory and orbits which the Lunar Orbiter would fly. Its work confirmed the limited extent of knowledge about the Moon's selenodetic environment and the potential hazards inherent in certain kinds of orbit designs. In its pioneering work it could little imagine the dramatic discovery in 1967 by Lunar Orbiter V of mass concentrations under the great maria of the Moon. The Working Group on Selenodesy provided MacDonald with a firm basis of fact for his argument that selenodetic instrumentation was a must on the Lunar Orbiter spacecraft.⁵ A group led by William H. Michael at the Langley Research

³Lunar Orbiter Discussion with Gordon MacDonald, September 24, 1963, Memorandum to the Record, October 2, 1963.


⁵Ibid.
Center finally designed the Lunar Orbiter selenodesy experiment, and their efforts were more than rewarded by the data acquired during the extended missions of all five Lunar Orbiters. Indeed the selenodetic data of the Moon which the program obtained has gone far to explore the nature of lunar gravity and the resulting perturbations in the spacecrafts' orbits and when taken with the data from the five successfully landed Surveyors, has provided the Office of Manned Space Flight very reliable, indispensable information for the Apollo Program.

In addition to selenodesy the Planetology Subcommittee selected two other fields of scientific investigation for experiments on the first five Lunar Orbiters which made up Block I of the program. This produced the radiation and micrometeoroid experiments, purposefully included to measure the performance of the spacecraft. At Langley Dr. Trutz Foelsche designed the Lunar Orbiter radiation experiment to measure the flux of radiation at the film cassette and at the cameras in the photographic system. The intensity of radiation from the Sun and in the radiation belts around the Earth made it necessary to shield the film, especially in the event of a solar flare, because of the danger of "wash out" which would render the film useless. This fact had Foelsche and Samuel Katzoff of Langley worried because the Eastman Kodak-designed photo system provided only aluminum shield-

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6 Telephone interview with Samuel Katzoff, Langley Research Center, August 24, 1967.

7 Originally the Lunar Orbiter Program had envisioned two blocks of spacecraft, but the lack of funds ended the development of more sophisticated Orbiters of Block II. A sixth flight spacecraft existed and could have flown after Lunar Orbiter V. However, costs of the Program's flight operations forced top NASA management to rule this out.
ing at two grams per square centimeter at the cassette and at two-tenths of a gram per square centimeter in the rest of the system, and although Foelsche desired thicker shielding the contractors maintained that the film would be safe. Foelsche convinced Clifford Nelson, the Langley Lunar Orbiter Project Office Director, that the spacecraft needed his radiation experiment. Nelson's office concurred and Foelsche was able to incorporate two small measuring devices to monitor the radiation flux in the spacecraft's photographic system. This later enabled NASA scientists to ascertain some of the conditions under which Lunar Orbiter photography was conducted, but weight restriction precluded a more sophisticated radiation experiment.

The third and final non-photographic experiment which the Planetary Subcommitteee approved for the Block I Lunar Orbiters consisted of a number of pressure cells to measure the flux, momentum, and energy of micrometeoroids in the near lunar environment. Designed by Charles A. Gurtler and William H. Kinnard of the Langley Research Center, the micrometeoroid experiment was presented to the OSSA Space Science Steering Committee on October 5, 1964. After reviewing it the Committee pointed out that the instrumentation was omnidirectional and limited in the quantity of data it could acquire. The Committee requested Gurtler and Kinnard to examine the kinds of similar instrumentation which the Surveyor and the Mariner C spacecraft had and to contact W. Merle Alexander at the Goddard Space Flight Center for specific as-

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8 Telephone interview with Samuel Katzoff, op. cit.
sistance in the further study of the experiment's requirements since he was the principal investigator for micrometeoroid instrumentation on these two spacecraft.9

Although the micrometeoroid, radiation, and selenodetic experiments were the only three which the Block I spacecraft eventually flew, the Lunar Orbiter Program Office was planning a greater number of more sophisticated scientific experiments for the Block II Orbiters. They included: (1) a gamma ray experiment to determine the presence and relative abundance of natural long-lived radioisotopes on the surface of the Moon, (2) an infrared experiment for mapping the lateral variations in the Moon's surface temperature, (3) a bi-static radar experiment for determining the average radar cross-section, surface roughness correlation functions, altitude measurements, reflectivity, and the dielectric properties of the lunar surface, (4) a photometry/colorimetry experiment to determine variations in the photometric function and the color of lunar surface materials, (5) a radiometer experiment for measurement and determination of lunar surface thermal gradients, (6) an X-ray fluorescence experiment to detect the relative abundance of iron and nickel on the Moon's surface, (7) a solar plasma experiment to study the spatial and temporal flux variation and energy distribution of low energy protons and electrons of the plasma, (8) an experiment to investigate the magnetic field in the vicinity of the

9Memorandum from Dr. Homer E. Newell, Associate Administrator for Space Sciences, to Dr. Floyd L. Thompson, Langley Research Center, October 23, 1964.
Moon, and finally (9) a lunar ionosphere experiment to determine the presence of a low density ionosphere in the immediate vicinity of the Moon's surface.\textsuperscript{10}

These experiments, spanning a wide range of scientific fields of investigation, demonstrated that the Lunar Orbiter Program Office envisioned in the Block II Orbiters a series of spacecraft which would conduct primarily scientific investigations and not necessarily more photography of the lunar surface. NASA had already designated the Block I Orbiters for missions which would gather photographic data of the lunar surface vital for mission planning of the Apollo Program. Moreover, the first Lunar Orbiters would explore some aspects of the Moon's environment and complement the work which the Surveyor spacecraft would carry out when they landed on the Moon. The Orbiter concept, expanded in a second series of spacecraft, could win for America major advances in knowledge of the Earth's natural satellite, a philosophy consistent with the mainstream thinking in the Office of Space Science and Applications. However, the lack of funds eventually precluded the Block II Orbiters and curtailed a major U. S. scientific thrust in exploring the Moon.

A third vital area of the Lunar Orbiter Program was mission design, and success in this planning depended heavily upon smooth coordination among the various NASA and industry participants in a fourth area, that of schedules and interfaces. Schedules concerned

\textsuperscript{10}Unmanned Lunar Orbiter Scientific Missions, a summary by Martin J. Swetnick, Lunar Orbiter Program Scientist, November 17, 1964.
job assignments for the program's various task groups; interfaces concerned the ways in which the many aspects of the program affected one another. Since these two areas are closely related, each having an impact on the other, it is appropriate to discuss mission design and schedule/interface problems together. Although some detailed consideration had been given during contract negotiations to ways and means of using NASA's capabilities to facilitate Boeing's work, the first major meeting to discuss actual schedules and interfaces convened on April 15, 1964, at the Langley Research Center. The purpose of the meeting between representatives from NASA Headquarters, Langley, the Lewis Research Center, the Jet Propulsion Laboratory, and the Boeing Company was two-fold. First they had to work out a basic agreement about the delegation of responsibilities which had not yet been assigned. This included tentative declarations by each party of its capabilities and limitations and what tasks each believed it could best perform to contribute to the success of the program. Secondly, the representatives of the various centers and the prime contractor had to agree on implementation of the decision in the first area of agreement.

Thomas Yamauchi of the Boeing Company began the talks with a presentation of a condensed project schedule and noted the time intervals in which Boeing would require trajectory information from the

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11 Memorandum to the Record, Summary of Lunar Orbiter Trajectory Meeting, Langley Research Center, April 15, 1964, (document dated April 17, 1964).
Lewis Research Center and JPL. Following this he outlined the type of information which Boeing would need.\textsuperscript{12} Dr. Karl A. Faymon of Lewis responded by specifying approximately the times before each launch when Lewis could deliver various preliminary and final data on launch vehicle check-out and performance. Faymon also explained to Yamauchi the times at which Boeing would have to supply data to Lewis on launch constraints, detailed mission profiles, and updated weight estimates. The two-way flow of information between the Lewis Research Center and the Boeing Company appeared not to present any serious problems at the time of the Langley meeting.\textsuperscript{13}

While things seemed to mesh well between Lewis and Boeing as far as launch vehicles, shrouds, adapters, and the spacecraft were concerned, the situation between the Jet Propulsion Laboratory and the Langley Research Center was more troubled. As of the April 15 meeting JPL had already committed all the necessary facilities of its Deep Space Network required by the Lunar Orbiter Program together with the effort needed to run them. However, the JPL people were also deeply committed to their own Ranger and Surveyor Programs, and this extra burden made them very cautious about accepting responsibilities beyond their capacity to perform them successfully. Thus when Langley had requested additional support for Lunar Orbiter from JPL on April 2, it met with

\textsuperscript{12}Information was not specifically enumerated in the document.

\textsuperscript{13}Summary of Lunar Orbiter Trajectory Meeting . . . , \textit{op. cit.}, p. 1.
firm resistance.\textsuperscript{14}

Langley had already received the commitment of the Jet Propulsion Laboratory's Deep Space Network, but on April 2 had further requested of NASA Headquarters that JPL take on the responsibility "for the programming of all operational computer programs, including reviewing the physical and engineering problems they represent, their mathematical formulation, and the formal requests for programming." This was not all. Langley wanted JPL to "make a definitive study of Lunar Orbiter tracking data requirements, including the accuracy of real time trajectory determination, considering tracking sites, data types, sampling rates, data noise biases, site errors, etc."\textsuperscript{15} As if this were not enough the Lunar Orbiter Project Office at Langley wanted JPL to "check the Space Flight Maneuver Specifications Tables; i.e., the guidance philosophy for midcourse, deboost, and retro firing including numerical firing tables which will be used in DSN operations."\textsuperscript{16} Boeing, at the same time, was to conduct a similar study of tracking and data acquisition requirements and was to review all JPL support work. When Langley Director Floyd L. Thompson had presented these expanded requests to Marshall Johnson, the Director of the Deep Space Network, and Victor Clarke, also of JPL, they had reacted favorably but had stipulated that

\textsuperscript{14}\textit{Memorandum from Floyd L. Thompson, Director of the Langley Research Center, to Homer E. Newell, Subject: Request for additional support for Lunar Orbiter from Jet Propulsion Laboratory, April 2, 1964.}

\textsuperscript{15}\textit{Ibid., p. 1.}

\textsuperscript{16}\textit{Ibid.}
the Systems Analysis Section and the Computer Applications and Data Systems Section at JPL would require more manpower to perform the Lunar Orbiter work. 17

By the April 15 Trajectory Meeting at Langley the position of the Jet Propulsion Laboratory had become more inflexible because of its own pressing responsibilities to Ranger and Surveyor. While it desired to assist the Lunar Orbiter Program, it did not want to do large quantities of time-consuming work such as computer programming. Moreover, JPL did not want any responsibility for approving formulations and calculations performed by other organizations. Independent checking of the various tracking and data acquisition requirements was a wise move, but JPL recommended that such checking be done it elsewhere. The Jet Propulsion Laboratory made/quite clear that it was not going to accept extensive responsibilities merely because it had a highly developed systems analysis and data acquisition capability. To counter Langley's request for more support it proposed a multi-stage program to educate Boeing and Langley personnel so they could conduct these tasks. Finally JPL proposed that Boeing set up a facility to "resemble" the Space Flight Operations Facility and run its own programming while having a private contractor check it independently. The Jet Propulsion Laboratory would assist as a consultant, but it did not want to carry the ball. 18

17Ibid.

biter Project Office requested that it put its informal proposal in formal terms for further review.

Langley and JPL proceeded to work out a compromise to facilitate the timeliest interface of schedules, but the actual problems of mission design and orbit determination still remained. Boeing's Lunar Orbiter Project Office had assigned Thomas Yamauchi to coordinate planning with the LOPO at Langley. On June 10, 1964 a major meeting convened at NASA Headquarters to review the status of Yamauchi's work, the proposed first mission, and the technical problems which placed constraints on the design of that mission. It had become apparent to Scherer, Kosofsky, and Swetnick of the NASA Lunar Orbiter Program Office that a dichotomy existed between the requirements of the short-term photographic mission and the extended selenodetic mission of the spacecraft. This dichotomy affected design of the attitude control system since its performance could determine the orbital parameters of the spacecraft during the long-life mission, which was to last about one year after termination of photography and readout.19

Captain Scherer outlined the first tentative Lunar Orbiter mission to the participants of the meeting as an introduction to the areas of difficulty. Mission A, as it later was called, would inject an Orbiter into a nearly circular orbit approximately 925 kilometers above the Moon with an inclination of 21° to the lunar equator. From here

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it was proposed to change the orbit to an ellipse ranging from 925 kilometers at apolune to 46 kilometers at perilune because this would be most satisfactory for conducting high and medium resolution photography.\textsuperscript{20} However, Gordon MacDonald of UCLA expressed some doubt about the safety of the spacecraft at such a low perilune over a period of one year. His reasoning was based upon the fact that the attitude control system would cause periodic perturbations in the orbit by the repeated firing of its jets. This could cause a \textit{3 meter change in the perilune per orbit}, as a Boeing study revealed.\textsuperscript{21} Such a change, according to MacDonald, would be too great over the long run for the attitude control system to handle, and this could jeopardize the long-life mission. He suggested that Boeing perform a detailed analysis of the system. The other members of the June 10 meeting agreed that Boeing should examine the following questions:

1. What deadzone can the Lunar Orbiter attitude control system accept on an extended life mission?

2. What will be the effects of the control jets on the motion of the Lunar Orbiter?

3. Can the impulses on each control jet be measured and counted, even during the time the spacecraft is not within line of sight telecommunications to earth?

4. What possible effects can an imbalance, such as the high gain antenna on the end of a boom, have on the attitude of the Lunar Orbiter over an extended lifetime mission?

5. Is it possible to modify the design of the attitude control system to operate coupled pitch and yaw jets? \textsuperscript{22}

\textsuperscript{20}Ibid.

\textsuperscript{21}Ibid., pp. 3-4, (phrase underlined in the document).

\textsuperscript{22}Ibid., p. 5.
The Boeing Company went to work on these five items, and by
the First Quarterly Review at the end of August, the spacecraft de-
sign was beginning a three-stage metamorphosis which would result in
the final configuration in the spring of 1965. The metamorphosis can
be briefly summarized as it occurred through April 1965. Initially
the spacecraft had a barrel-shaped photographic package, attitude con-
trol jets located on the bottom deck, and attitude thrusters for sta-
bilization during a burn of the velocity control engine positioned on
two
the ends of the solar panels. At stage /the spacecraft had a more
efficiently shaped photographic package with a flat bottom for better
thermal control. An arch from the lower to the upper deck had been
placed over the photo package to add strength, and the structure of
the propulsion system had been changed. However, the attitude control
thrusters still remained at the tips of the solar panels. The third
stage of the metamorphosis revealed a swiveled velocity control engine
and greater room for the nitrogen tank to fit down in the center of
the propulsion module on the upper deck. The attitude control jets had
been moved to the upper deck, the omni-antenna boom had been strength-
ened, and the micrometeoroid detectors had been placed around the mid-
dle deck.23

While Boeing was resolving the conflicts between orbital require-
ments for photography and those for the one-year extended mission, the
Langley Research Center and the Jet Propulsion Laboratory arrived at a

satisfactory compromise in the matter of JPL support. At the beginning of July 1964, JPL and Langley officials worked out detailed plans for educating select Langley and Boeing personnel in mission analysis, programming standards, and the review of existing programs that might benefit Lunar Orbiter. This training began on July 15 and afforded the Lunar Orbiter Program the opportunity to solve its own problems of analysis without unduly taxing JPL manpower. Boeing was very willing to learn from JPL, a fact which facilitated the implementation of the Langley-JPL compromise.

It is timely at this point in the examination of mission design and schedule/interface problems to discuss the several kinds of reviews and tests used in the Lunar Orbiter Program, beginning with the spacecraft design phase just described. The first stage of the review process was the Preliminary Design Review conducted by NASA and Boeing. This review was always held to check any specific technical area or major subsystem before NASA and Boeing made the decision to freeze the design. If agreement was reached NASA gave Boeing the go-ahead to fix the design, and once this had been done both met to hold a Critical Design Review. Here the item, be it a component or a major subsystem, was picked apart or passed as acceptable for fabrication and testing. If approved, the item was procured or fabricated, and after this point NASA tried to hold changes to an absolute minimum. Dur-

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24 Memorandum from Lee R. Scherer, Lunar Orbiter Program Manager, to Oran W. Nicks and Edgar M. Cortright, Subject: Immediate need for JPL support for Orbiter, July 10, 1964.
ing the fabrication stage various forms of reviews took place until an item was completed and tested. At the completion point a formal NASA Acceptance Review was conducted.25

Not only did the Lunar Orbiter Program conduct a constant series of reviews, but it also operated on a very well developed testing philosophy aimed at making the first mission a complete operational success. Because the testing procedure played so vital a part in the program and because it reflected a very positive attitude among the entire NASA-Boeing team, it deserves a brief description. At the beginning of the whole testing procedure all components of the spacecraft system went through a Flight Acceptance Test (FAT) which exposed them to "nominal" operational environments such as vibration, temperature, and vacuum. Three of each component then were divided into sets A, B, and C for more specific tests. Set A was used for qualification tests which simulated overstress conditions. This kind of test was designed to push the component beyond expected limits to determine what punishment it could actually withstand. Set B underwent reliability demonstration tests which simulated two real-time missions at the FAT level. Finally Set C components made up subsystem assemblies which were tested and then integrated into a complete spacecraft (Spacecraft "C"). This first complete spacecraft system was subjected to compatibility tests with

the Atlas-Agena launch vehicle, the tracking and communications network at Goldstone, California, and with the Eastern Test Range tracking and communications facilities at Cape Kennedy.26

The Lunar Orbiter Program built a total of eight spacecraft including Spacecraft "C" which was the integrated system of the third set of components. Following Spacecraft "C" came Spacecraft 1 and 2. Number 1 underwent qualification tests at spacecraft level while Number 2 was subjected to thermal vacuum tests for a time period covering two missions. The other five Lunar Orbiters were put through Flight Acceptance Tests and then sent to the Eastern Test Range for their final checkout and launch.

Clifford Nelson pointed out in his paper presented at the XVII International Astronautical Congress that no serious problems or failures were experienced during all spacecraft-level tests. This testified to the standards and the thoroughness which had been used in testing at the component level. Faulty equipment had been effectively rooted out and potential problems in subsystem integration had been exposed early in the testing phase of the program.27 More interesting, however, was the fact that testing was carried out in a parallel mode rather than in a series mode. This was largely due to the tight schedule and the spartan economy which NASA and Boeing practiced during the course of the design and testing phases. Thus, for example, the three

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26 Ibid., Figure 5 - Lunar Orbiter Test Program.
27 Ibid., p. 8.
sets of components (A, B, and C) and the seven spacecraft were tested in time periods which substantially overlapped.

This short survey of the review and testing procedures used by the Lunar Orbiter Program brings us back to the actual events of the last quarter of 1964 and the first half of 1965, the time period when designs were finalized and procurement and fabrication begun. Several problem areas had developed which threatened the original schedules and objectives of the program. Some of these have already been mentioned. Two more are, however, noteworthy. At the Lunar Orbiter Preliminary Design Review held at Boeing on October 27 and 28, 1964 the status of the micrometeoroid and radiation experiments had somewhat alarmed Martin J. Swetnick, the Lunar Orbiter Program Scientist from NASA Headquarters, and Israel Taback, the LOPO Spacecraft Manager. To them the instrumentation which Boeing proposed for the two experiments by letting bids either to Space Technology Laboratories or Texas Instruments Inc., did not meet the actual specifications for the experiments. Indeed they felt that even the specifications document which Boeing had drawn up did not demonstrate an understanding of the experiments which the Lunar Orbiter Project Office desired to have onboard the spacecraft.

Swetnick called a special meeting with Boeing representatives on October 29 for a detailed discussion of Boeing's approach to the experiments. He and Taback made clear to the contractor that the specifications document for the radi-

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The radiation experiment was very confusing because "it did not in any way provide the bidders with a description of the requirements for the radiation data, a statement of objectives, and a description of what should be done." Boeing's lack of knowledge about the radiation experiment rather startled Swetnick and Taback who urged Boeing to work out a more realistic approach to fabrication and testing of the experiment's instrumentation.

The special meeting on October 29 brought to light an even more serious matter with a potential for causing further difficulties. It seemed that the main problem concerning the experiments was not lack of ability, for certainly Boeing had this or could obtain competent support. Instead it was poor communications between Langley and Boeing. With this issue out in the open, Boeing representatives realized that they needed to modify the specifications document to give their bidders a much clearer idea of exactly what they and NASA wanted. They also stressed that they would send the modified document to Langley for review and approval before submitting it to the bidders.

As for the micrometeoroid experiment, Boeing had made certain changes without notifying the principal investigator on the experiment, Charles A. Gurtler at Langley. Swetnick was disturbed that Boeing had decided to locate the micrometeoroid pressure cells on the

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periphery of the tank deck outside the thermal blanket. This would necessitate reducing the number of cells from 20 to 15. Worse yet, the leads from the cells to the respective electronics would create a temperature control problem because they would have to pass through the thermal blanket. Swetnick made it clear that Langley would have to examine this proposed alteration very carefully before a decision could be reached. Gurtler did not believe that the experiment could be useful with fewer than 20 cells, and any change would require a substantial trade-off. Again the fact that Langley officials were unaware of Boeing's thinking on the micrometeoroid experiment showed a surprising lack of communication, and steps were subsequently taken to strengthen the ties between LOPO and Boeing.

The second problem of note was the status of the Lockheed Agena-D vehicle, its adapter, and the spacecraft shroud -- all of which were the responsibility of the Lewis Research Center. Early in 1964 Lewis had insisted that Lockheed should handle the entire integration of the booster-adapter-shroud hardware for Lunar Orbiter. Langley had proposed to have Boeing provide the adapter and the shroud. This arrangement had not been acceptable to Lewis. Abe Silverstein, the center's director, had personally guaranteed that the adapter and shroud would be delivered to the Boeing Company at the time stipulated in the contract. By late 1964 Lewis was confronted with the predicament that

Lockheed, as the sole vendor of the hardware, was in a position to exploit the situation and charge possibly as much as 100% overrun in order for NASA to meet its schedule with Boeing. Lewis, realizing this, was tempted to open the field to competitive bids for the hardware, but it had to await a Headquarters review of the situation before making such a move. 32

The Lunar Orbiter Program Office was disturbed by the unforeseen turn of events at Lewis. Lockheed had failed to provide Boeing with an adapter master gauge on December 1, 1964, as it had promised; and Boeing still did not have one by January 5. Worse yet Lewis had not finalized the adapter design by the first of the year, and this would impinge upon program schedules unless NASA Headquarters quickly altered the situation. Boeing, meanwhile, had sent Lockheed a model of the spacecraft on January 4 for separation tests with the Agena, but it remained uncrated pending a decision by NASA to open the field for competitive bids for the adapter and the shroud. 33

The Lewis Research Center prepared to contract with Lockheed for another series of Agena launch vehicles on April 15, 1965, a mere fourteen months from the scheduled first Lunar Orbiter launch date. In the past Lockheed had generally required eighteen months to fill such an order, and in this case the lack of a procurement plan for the adapter and the shroud further complicated the situation. Lockheed estimated that it would require about 18½ weeks to build these two items of hard-

32 Ibid., p. 2.
33 Ibid.
ware and another 2\(\frac{1}{2}\) to 3 months for testing.\(^{34}\) Even if NASA decided to let another aerospace company build the adapter and the shroud, Lewis still planned to have Lockheed integrate these items with the Agena system. This meant that the Langley Lunar Orbiter Project Office might have to deal with three different contractors in the launch vehicle-spacecraft interface alone.

The worst aspect of the whole Lewis-Lockheed dilemma was that no other aerospace firm, starting from scratch, could produce the Lunar Orbiter adapter and shroud in less time than it would take Lockheed to do the job, and this meant at least seven months. As a result the scheduled delivery date for the mission-peculiar hardware, July 1, 1965, would not be met, and if the situation worsened, Boeing would have every right to claim default on the part of the Government. Scherer saw the necessity to resolve the predicament at the highest NASA management level to untangle an increasingly confusing relationship between Langley, Lewis, and the contractors before it got completely out of hand.\(^{35}\)

While NASA Headquarters grappled with the management situation underlying the launch vehicle-adapter-shroud problem, the Lunar Orbiter Program Office proceeded to hold the Third Quarterly Review between February 24 and 26. During this time three meetings convened to review the status of the spacecraft, the results of the Critical Design

\(^{34}\)Tbid.

\(^{35}\)Tbid., pp. 3-4.
Reviews and the interfaces of the various program systems (i.e., spacecraft, launch vehicle, tracking and data acquisition, etc.). Boeing made known that the late availability of hardware from Eastman Kodak and RCA had necessitated a schedule adjustment moving prototype systems tests back eight weeks. This development did not change the first launch date because of the use of the parallel testing mode. However, the program deleted the FAT on Spacecraft Number 1 and established testing restraints to fit the schedule change.36

Boeing reported all designing essentially completed and the completion of a substantial amount of structural and thermal testing. These efforts had revealed no serious failures or deficiencies in the components. A few items did present problems: the design and operation of the camera thermal door, telemetry data handling during testing, the photographic recording equipment at DSIF site 71, and several potential trouble areas in the spacecraft's film processing system. These items were being resolved and did not threaten schedules or hinder progress in any substantial way. The situation at Lewis was being carefully monitored by NASA Headquarters, and the Boeing Company had decided to bid for the shroud.37 Finally the men present at the Third Quarterly Review decided to have Boeing conduct "qualification tests on S/C 1, one mission simulation test on S/C 2, and phase one of the Goldstone test on S/C 3 . . . prior to start of FAT on the first flight.


37Ibid., pp. 4-5.
By early March the Lunar Orbiter Program Office had altered the testing program, removing several conservative features in the initial phase of testing to allow further schedule compression. At the same time restraints were established which required that
1) the qualification and reliability tests of each component for a flight spacecraft had to be completed before the Flight Acceptance Test on the component could begin, and that
2) no FAT of an entire flight spacecraft would commence before the completion of qualification tests on Spacecraft 1, of one mission simulation test on Spacecraft 2, and of the first phase of the Goldstone test on Spacecraft 3.

These steps left very little room for any major testing failures without causing serious schedule slippages. This was a risk, but one which was calculated upon testing procedure at the component level to catch and correct any anomalies before they could reach serious proportions and jeopardize the program's timetable.

An example of the early detection of such an anomaly had arisen during the February 17 Photographic Subsystem Critical Design Review. Leon Kosofsky, the Program Engineer, reported to Israel Taback, the Lunar Orbiter Spacecraft Manager at Langley, in a memorandum dated March 4 that "the film processor cannot be stopped indefinitely without the risk of losing the mission due to the sticking of the Bimat web to the exposed

\[^{38}\]Ibid., p. 2.

This condition meant that either the processor or the mission design would have to be altered. At least some film would have to be wasted to keep the whole film and Bimat web advancing at a rate sufficient to preclude any sticking. The Lunar Orbiter Program Office had to determine the actual safe time the two surfaces could remain in contact during a non-photographic period. Kosofsky pointed out that, as matters stood, if this time were $3\frac{1}{2}$ hours or less, then a typical mission such as that envisioned in Bellcomm report TR-65-211-1 (January 25, 1965) would be impossible. If the safe time were between $3\frac{1}{2}$ and $6\frac{1}{3}$ hours, waste exposures would be required on every non-photographic pass. This was due to the forty minute processing period which could be subtracted from the time requirement of the two passes. Finally, a safe time of $7\frac{1}{2}$ hours meant that wasted exposures would only be required on alternate passes during non-photographic periods, while a safe time of $10\frac{1}{2}$ hours would allow two successive passes during such periods without having to waste film. Nevertheless, this single problem presented sufficient potential impact upon Lunar Orbiter's mission capabilities to require immediate study of ways to reduce or eliminate film wastage regardless of the final processor safe time.

The amount of time wasted in the readout process due to blank pic-

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41 Ibid.
tures presented one of the worst aspects of the film advance problem. As of Kosofsky's March 4 memorandum the design of the photographic system precluded any acceleration of the rewind drive. Unless changed this would severely affect the critical readout process. Kosofsky instructed G. Calvin Broome, head of the Photo Subsystem section of LOPO, to explore ways of overcoming the necessity to waste film and thus prolong the readout process. 42

Except for several minor problem areas the Lunar Orbiter design phase was completed by April 13, 1965. Over 80% of the procurement had been started and over 60% of the first sets of components had been delivered to the contractor. Development tests had begun and mission planning for the Orbiter was just commencing. The Kent facility at Boeing in Seattle also neared completion. Boeing would use it for the spacecraft's mission simulation tests. It consisted of a major chamber with a working section 39 feet high by 29 feet in diameter capable of being pumped down at twice the rate of the planned Lunar Orbiter ascent profile for the mission simulation tests. Other smaller chambers were also part of this testing facility. 43

By the middle of 1965 the Lunar Orbiter Program was well into its major development phase. The Program Office and the Project Office at Langley were maintaining an equilibrium between the many different needs

42 Ibid., p. 2. See also memorandum from SL/Engineer, Lunar Orbiter Program, to SL/Manager, Lunar Orbiter Program, March 11, 1965.

which had to be fulfilled, between the working groups at Langley, Boeing, the Jet Propulsion Laboratory, Lewis, and the major subcontractors. They maintained tight control on the amount of funds and the rate of funding required by the prime contractor. Langley and NASA Headquarters continued prodding, questioning, investigating, and conferring among themselves and the other NASA centers and the contractors. This helped program management to avoid costly schedule slippages.
CHAPTER VIII

LUNAR ORBITER MISSION OBJECTIVES AND APOLLO REQUIREMENTS

While NASA and Boeing accelerated the construction and testing phase of the program, the work of designing the Orbiter missions brought the Office of Space Science and Applications and the Office of Manned Space Flight to a long series of plenary meetings and task group assignments. Accordingly the evolution of mission planning constitutes the major subject of this chapter.

In a memorandum dated November 3, 1964 Dr. George E. Mueller, Administrator of OMSF, had requested of Bellcomm answers to two items fundamental to Apollo site selection: (1) "Who... is responsible for lunar site analysis and selection?" (2) "We are going to need a place in which to store the films, etc."

Bellcomm reviewed the status of work related to lunar site analysis and selection. This became the basis for the organization of the Surveyor/Orbiter Utilization Committee. Bellcomm reported to Mueller's office on December 23, 1964, and pointed out that Apollo landing site selection was a function of OMSF. It had the responsibility of defining strategies, goals, schedules, and trajectories with OSSA. The report suggested that OMSF form a working group charged with:

a. Examining the problem of lunar site analysis and selection.

b. Recommending the initiation of any work necessary.

c. Making recommendations on any new facilities needed for the adequate analysis and storage of the data.
d. Examining the necessary funding and identifying the responsible organizations.

e. Identifying the manner in which landing site selection should be accomplished.  

The proposed working group would consist of a chairman reporting Associate Administrator either to the /of OMSF or the director of the Apollo Program. The Office of Space Science and Applications would assign representatives from the Surveyor and the Lunar Orbiter Programs. The Manned Space Flight Center would assign representatives from the Apollo Spacecraft Project Office, the Flight Operations Division, and the Flight Crew Operations Division. Manned Space Flight Operations and Manned Systems Engineering (OMSF) together with the Bellcomm Site Survey Group would also appoint representatives to the group. Lastly the Bellcomm memorandum recommended that Myron W. Krueger, the OMSF man responsible for lunar photographic data, be assigned.² This would form the nucleus of the more formal Surveyor/Orbiter Utilization Committee which came into being at a later date.

As of December 23, 1964, the Office of Manned Space Flight had no organization to accept and store Surveyor or Lunar Orbiter data. No organized group existed to perform lunar site analysis and selection. The Apollo Project Development Plan (PDP) stated the need for a working group to make recommendations to the appropriate groups within OMSF on the optimum utilization of data, but no such group had


²Ibid.
been set up. On the other hand the Lunar Orbiter Program Office had already set up a working group to make recommendations on the form of data and its storage and retrieval. Bellcomm also had a site survey group which monitored site survey programs for Lunar Orbiter and Surveyor and which developed strategies for the use of the systems in these programs. The time had come for the Office of Manned Space Flight and the Office of Space Science and Applications to form a firmer working relationship.

On September 22, 1964, Oran W. Nicks had informed Apollo Program Director, General Samuel C. Phillips, about the mission planning effort which the Lunar Orbiter Program was undertaking since this would possibly influence hardware design. He suggested that OMSF make a study of specific Lunar Orbiter missions in support of Apollo. The recommendations of the study would aid the Lunar Orbiter Program Office in developing actual missions. Nicks pointed out that Bellcomm had very qualified men to perform such a study for OMSF.

Nicks's memorandum resulted in a Bellcomm study for OMSF during the remainder of 1964. On February 18, 1965, Phillips sent Nicks the report of the study entitled "Lunar Orbiter Mission Planning" by Doug D. Lloyd and Robert F. Fudali of Bellcomm. Phillips expressed a willingness to have further joint study done if Nicks agreed that it was

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necessary. 5

The Lloyd-Fudali report explained that Lunar Orbiter had the capability to conduct nearly identical photography in different ways, the two simulated missions being laid out, one posigrade, the other retrograde. Furthermore, the study had reached the following conclusions:

1. The strategy of contiguous high resolution photography of multiple targets should be used. This allows successful Apollo site survey with only a single Lunar Orbiter.

2. To allow the above, the camera sequencer control should be changed to include a quantity control for providing eight consecutive photographs.

3. The quantity of gas made available for the attitude control system should be sufficient for a minimum of sixteen separate photographic maneuvers.

4. To achieve at least 1 meter/optical pair resolution, photographs should be taken from a nominal height of 46 km or less.

5. To avoid the possible problem of orbital instability for the above low altitude orbit due to the uncertainties in our knowledge of the moon's spherical harmonic terms, it is recommended that the orbit be inclined no more than $7^\circ$ to the lunar equator. 6

Further Bellcomm research during March 1965 produced a paper entitled "Apollo Lunar Site Analysis and Selection" which was transmitted to General Phillips. Pointing out that Lunar Orbiter and Surveyor were the two prime data gathering systems for Apollo, it recommended that

5Memorandum from MA/Apollo Program Director to SL/Lunar and Planetary Programs Director, February 18, 1965.

OMSF and OSSA set up a joint Site Survey Steering Committee. Its major task would be the definition of the objectives and the use of Lunar Orbiter and Surveyor for the Apollo Program's needs. The committee would have the responsibility for target selection, launch schedules, choice of measurements, measurement priority and instrument complement, control of data handling, and recommendations on data analysis on each Lunar Orbiter and Surveyor mission.7

On May 10 Brian T. Howard of Bellcomm reported to General Phillips that in addition to earlier recommendations for Lunar Orbiter and Surveyor tasks in Apollo site selection, Bellcomm had considered two more proposals related to the organization of cooperative OMSF/OSSA activities in site analysis and selection. First, it seemed highly desirable to set up a joint OMSF/OSSA Lunar Surface Working Group. It would report to the Apollo Program Office and to the Lunar and Planetary Programs Office. It would coordinate mutual planning activities concerning site survey requirements and the ways in which they could be satisfied. Secondly, Bellcomm recommended that the Manned Space Flight Center's Data Analysis Division subcontract with JPL for the prime responsibility of gathering, analysing, and evaluating data.8

While Bellcomm was advising OMSF the Langley Lunar Orbiter Project Office carefully studied and compared the proposed missions which Bellcomm


had developed (the Lloyd-Fudali report) with the one developed by Boeing. Thomas Young of the LOPO informed Norman L. Crabill of the conclusions pertaining to the reliability of each proposed mission on May 7. His memorandum stressed the differences in reliability inherent in the studies performed by Bellcomm and Boeing. The Bellcomm mission required 4.5 days longer to accomplish than did that of Boeing, but the variation in resulting data was minimal.9

Young’s LOPO mission planning study group continued to analyze Lunar Orbiter capabilities and concluded in a report to Norman L. Crabill on June 14 that Apollo and Surveyor requirements allowed Lunar Orbiter variable mission types ranging from a concentrated to a distributed photographic mission, depending upon primary requirements for the two programs. The differences in obtaining data and in resolution of photography indicated in LOPO studies did not significantly affect the mission type. Thus all Lunar Orbiter flights could be defined without consideration of the type of mission required to meet predetermined objectives. However, LOPO considered the establishment of mission objectives as a prerequisite to further mission planning.10

On Friday, June 25, representatives from OSSA, OMSF, Bellcomm, the Jet Propulsion Laboratory, the Manned Space Flight Center, and Langley met for the initial coordination meeting to establish a preliminary


plan for utilizing Lunar Orbiter's mission capabilities with the first Lunar Orbiter mission, the first Surveyor mission, and with Apollo mission requirements. During the meeting it was agreed that Lunar Orbiter which had could best aid Surveyor by screening sites and defining targets /a high probability of being smooth. The representatives from the Apollo Systems Engineering Office (MAS) stated that Lunar Orbiter, with one-meter resolution, could photograph a landed Surveyor from an altitude of 46 kilometers because of the Surveyor's shadow at a prescribed Sun angle and its high albedo. Lunar Orbiter had originally been targeted to screen Surveyor sites and, after a Surveyor had successfully landed, was to overfly it and photograph it in high resolution. The increased capabilities of the Lunar Orbiter photo system now allowed it to combine screening and overfly tasks in the high resolution mode. 

The Apollo Systems Engineering Office and the Manned Space Flight Center (MSC) preferred that Lunar Orbiter fly a distributed mission; this offered a sampling technique better able to find any area suitable for the Apollo landing, to define suitable areas for further coverage on later Orbiter flights, and to increase the flexibility of the Apollo launch window by finding suitable sites spread across the Apollo zone of interest. Both MSC and Bellcomm recommended that Lunar Orbiter photograph the Ranger VIII impact point located in the Apollo zone because possibly it could serve as a future

11 Minutes: Lunar Orbiter Target Objectives Meeting at Langley Research Center, June 25, 1965, recorded by A. Thomas Young, pp. 2-3.
Apollo orbit anchor point.\textsuperscript{12}

The July 25 Langley meeting provided the Lunar Orbiter Project Office with information concerning mission objectives from the Orbiter, Surveyor, and Apollo Program Offices. This information assisted LOPO in mission planning, and it was better able to guide the Boeing Company in its work.\textsuperscript{13} The meeting produced the basis for efficient coordination between the NASA offices requiring Lunar Orbiter data and enabled the Lunar Orbiter Program to develop preliminary mission plans.\textsuperscript{14}

On July 13 to 15 a preliminary mission definition meeting for Lunar Orbiter convened at Langley. The men present\textsuperscript{15} defined preliminary Lunar Orbiter mission types on the basis of decisions rising out of the June 25 meeting at Langley. The mission types depended upon three basic flight objectives: (1) gathering significant topographic information of the Moon's surface for selection of Surveyor and Apollo sites; (2) providing selenodetic data on the size, shape, and gravitational properties of the Moon necessary for determining orbit lifetime of a Lunar Orbiter sufficiently long to allow adequate time for readout; and (3) providing

\textsuperscript{12}Ibid., pp. 4-6.


\textsuperscript{14}OSSA Review -- July 2, 1965, p. 3.

measurements of micrometeoroid and radiation flux in the lunar environment.16

By the end of July the Lunar Orbiter Program Office had the results of the Langley LOPO and Bellcomm preliminary mission studies. Four mission types had been formulated on the basis of requirements and recommendations from the Apollo, Surveyor, and Lunar Orbiter Program Offices. Briefly summarized they were: Type I, site sampling, a distributed mission allowing 11 single passes over different terrain types (i.e., highland, maria, rilles); Type II, wide area coverage for Surveyor of only three separate sites; Type III, Surveyor location mission to pinpoint landed Surveyor at one-meter resolution; and Type IV, a combination mission for more sophisticated work later in the program.17

A joint OSSA/OMSF Site Survey Meeting convened at NASA Headquarters on August 4 to review the status of the Surveyor, Lunar Orbiter, and Apollo Programs and to discuss preliminary mission planning for Lunar Orbiter and selection of Surveyor landing sites. Clifford H. Nelson, Lunar Orbiter Project Manager, summarized the status of the Lunar Orbiter Program and pointed out that the program expected to meet its original launch schedule but that slips in subsystems, especially the photo system, had necessitated further compression of the testing schedule in order to hold the launch schedule.18


After Nelson's report and the Apollo status report Norman L. Crabbill presented the preliminary planning for the first two Lunar Orbiter mission types. He outlined the ground rules:

**Ground Rules:**

1. photograph two sites of each smooth looking terrain class up to a total of eleven sites within the Apollo area of interest

2. photograph Ranger 8 and any landed Surveyors

3. each site will be photographed using a single pass with 16 contiguous 1 meter resolution frames per pass

4. readout of up to four frames between passes

5. mission must be defined for the Boeing Co. by the Fall of 1965

And for the Type II mission:

**Objectives:**

1. map topography for possible Surveyor sites

2. high precision selenodetic data

3. lunar environmental data

**Ground Rules:**

1. photograph 3 sites spread 30° of longitude apart

2. use 4 passes per site

3. use 16 high resolution contiguous frames per pass

At the August 4 meeting Lee R. Scherer proposed the establishment of a Lunar Photographic Analysis Steering Group which would act as a sounding board for suggestions and requests from the various programs involved in lunar exploration. It would also establish priorities and

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19 Ibid., pp. 5-6.
serve as coordinator for NASA-wide activities related to obtaining photographic data of the Moon. Such a group could coordinate such activities as control of Earth-based lunar mapping, direction and planning in the analysis of Lunar Orbiter data, monitoring of pertinent work for other government agencies, planning with the OSSA planetology group (SL), handling agreements for data processing priorities, and coordinating Apollo needs with other requirements. No final action was taken on the Scherer proposal at this time, but it stimulated discussion on these aspects of mission planning. 20

All the previously discussed plenary meetings served as the basis for setting up the OSSA/OMSF Ad Hoc Surveyor/Orbiter Utilization Committee (SOUC) which held its first meeting on August 20, 1965. 21 At this time Scherer reviewed the Lunar Orbiter photographic format and described the photo system in detail. Finally, he stressed these major points which had to be considered in the planning of Orbiter missions:

1. Resolution and area coverage are directly proportional to orbital altitude.

2. A photographic pass requires an attitude maneuver.

3. The system can take 1, 4, 8, or 16 pictures on a single pass.

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20 Ibid., p. 8.

21 Members of the Surveyor/Orbiter Utilization Committee were: Edgar M. Cortright (Chairman) OSSA, Samuel C. Phillips (Apollo Program Office) OMSF, Edward E. Christensen (Manned Operations) OMSF, William A. Lee (ASPO) MSC, William E. Stoney (Data Analysis) MSC, Oran W. Nicks (Lunar and Planetary Programs) OSSA, Urner Liddel (Lunar and Planetary Science) OSSA, Lee R. Scherer (Lunar Orbiter Program) OSSA, Benjamin Milwitzky (Surveyor Program) OSSA, Victor Clarke (Surveyor Project) JPL, Israel Taback (Lunar Orbiter Project) Langley.
4. The system is capable of taking 192 pictures total.

5. The last 4 pictures in the take-up spool can be read out on command anytime during the mission.

6. The system is capable of reading out one frame during each orbit. Pictures cannot be taken during the read-out.

7. The thread-up distance from the camera to the readout is 18 frames.

8. Total readout will be accomplished after completion of all photography; the last photograph taken will be the first read out.

9. Gravity perturbations and the latitude width of good lighting both increase with orbital inclination. There will have to be some trade-off studies made in this area; what's good for selenodesy doesn't produce the best pictures.22

Norman L. Crabill followed Scherer with an outline of the four mission types developed for Lunar Orbiter. Specifically they were: Type I, photographs ten evenly distributed target sites in the Apollo zone of interest and covers each site in high and low resolution stereo photography (1 meter and 8 meters); Type II, photographs 4 sites to screen for Surveyor landing sites in Apollo zone; Type III, photographs to one meter resolution an area containing a landed Surveyor to learn as much as possible about the surrounding terrain; Type IV, obtains a variety of topographic data not obtained by other mission types.23

The Committee agreed to let Scherer define the decisions and the dates for the next SOUC meeting. It requested Scherer to inform Boeing

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23Ibid., pp. 4-5.
to concentrate on studies of multiple and distributed targets instead of studying models involving large block photography of the Moon's surface. The Committee also asked Scherer to hold a working meeting of representatives from the Apollo, Surveyor, and Lunar Orbiter Programs to determine the preliminary plan for the first Lunar Orbiter mission. The Committee favored a distributed Type I mission and asked that a presentation of the first mission plan be made within 30 to 45 days. 24

The working meeting requested by SOUC took place at the Langley Research Center on September 8 and 9. It had the following major objectives: (1) to gain understanding of Orbiter and Surveyor mission design problems; (2) to review available data on the lunar surface; and (3) to produce lists of lunar sites which would satisfy Apollo, Surveyor, and Lunar Orbiter constraints. 25 At the meeting Scherer pointed out that Homer E. Newell, Associate Administrator of OSSA, would have to make the final decision on the first mission plan for Lunar Orbiter and that he would rely on recommendations made by SOUC. This necessitated the most detailed, well defined presentation of the plan by the Lunar Orbiter Program Office to the Surveyor/Orbiter Utilization Committee. 26

The Apollo Spacecraft Program Office (ASPO), represented by James Sasser from the Manned Space Flight Center, expressed its desire for a Lunar Orbiter distributed mission and concurred on the sampling of

24 Ibid., p. 5.
25 Lunar Orbiter Mission Planning Meeting, Langley Research Center, Bldg. 1251, Rm 105, September 8–9, 1965, Minutes recorded by A. T. Young.
26 Ibid., p. 1.
different terrain types within the Apollo zone of interest with emphasis on the areas of greatest apparent smoothness. However, ASPO did not want the Lunar Orbiter restricted to sampling Surveyor-size landing areas or sites accessible only to Surveyor. As a result Sasser accepted an action item to provide the Lunar Orbiter Project Office with a letter confirming the bounds of the Apollo zone of interest.  

Lawrence Rowan of the United States Geological Survey made a presentation to the members of the meeting in which he discussed the USGS lunar terrain analysis based upon the newest lunar map from the Aeronautical Chart and Information Center (ACIC) with a scale of 1:1,000,000. Rowan talked about the various sources of data that went into making the lunar map and then gave an interpretation of terrain types on the Moon. The USGS terrain analysis enabled Rowan to present a list of nine terrain types to be sampled by Lunar Orbiter: (1) dark mare, (2) mare, (3) mare ridges, (4) mare rays, (5) upland Unit-I, (6) deformed crater floors, (7) upland Unit-II, (8) crater rims, and (9) sculptured highlands. Rowan's information formed part of the basis for the site selection process which followed.

The members of the meeting subsequently developed two Orbiter missions based upon the USGS terrain map and the following assumptions: (1) orbital inclination equals 12.5°, (2) descending node photography, (3) orbital spacing based on Goudas model of the Moon, (4) lighting

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27 Ibid., p. 3.
28 Ibid., pp. 3-4.
band based on a spherical Moon, and (5) lighting band initially centered about the lunar equator at $0^\circ$ longitude. Two preliminary mission plans resulted. The men at the meeting picked these apart and criticized various aspects. Their major criticism was that the plans included too many samples of mare terrain types. They generally agreed that on the first mission Lunar Orbiter should only photograph the Apollo zone of interest unless a Surveyor landed outside of it.\(^2^9\) The results of the Langley meeting subsequently formed the foundation of the Lunar Orbiter Mission A plan.

On September 29, 1965, the Lunar Orbiter Program Office formally presented the Mission A plan to the Surveyor/Orbiter Utilization Committee. It would be a Type I mission, sampling various lunar surface areas in the Apollo zone of interest. Lunar Orbiter's cameras would assess selected sites for their suitability for Apollo and Surveyor landings.\(^3^0\) An excerpt from the OSSA Review briefly describes Mission A:

A few pictures will be taken on the initial orbit. The location could range from $60^\circ$ east to $110^\circ$ east and will be determined later. In the final orbit, ten separate sites will each be covered by a single photographic pass. Briefly, site one is the only example of a dark mare in the Apollo areas of interest. Dark mare are considered the smoothest of the various terrain types. Site two is a highland site with smooth basins. Site three is in the

\(^2^9\) Ibid., pp. 4, 7.

same longitude as Ranger VIII. It is a ray mare probably not quite as rough as shown by the Ranger photographs. Site four is a highland site which will contain photographs of each of the four highland terrain units. Site five, in Sinus Medii, has high potentiality for Apollo and Surveyor landing areas. Site six contains upland units and a deformed crater floor. Site seven is a good example of a mare with sinuous ridges. Site eight is a smoother mare with linear ridges. Site nine is located in the old crater floor Flamsteed and is probably the prime Surveyor landing site at this time. Site ten is outside of the Apollo area but is a dark mare and may be utilized for Surveyor.31

The Committee approved the plan.

After winning approval for the Mission A plan from SOUC Scherer made a presentation to a meeting of the Planetology Subcommittee of the OSSA Space Science Steering Committee on October 21 and 22. With him were Harold Masursky and Lawrence Rowan of USGS. Scherer reviewed the procedure for selecting the ten areas on the lunar surface which the first Lunar Orbiter would photograph. He stressed that the mission's objective was to obtain detailed topographic data for assessing the suitability of specific areas as possible Apollo and Surveyor landing sites.

Masursky explained in detail how the Lunar Orbiter Program could apply the methods of structural and stratigraphic geological mapping developed for Earth studies when these were augmented by telescopic observations and the Ranger pictures of the Moon. Rowan outlined recent findings concerning crater densities, surface roughness, and albedo of the Moon. He specifically described the ten selected areas which Lunar


Orbi~r would photograph on Mission A. He also stressed that the USGS work had led him to conclude that crater density measurements were not too useful in the selection of landing sites, but they aided in distinguishing between rayed and non-rayed surfaces. This, he pointed out, suggested a relationship between surface roughness and albedo.33

After the meeting the Planetology Subcommittee drew up a resolution, based upon the Lunar Orbiter Program Office's reports and the USGS information, which it forwarded to Oran W. Micks. Although the resolution did not influence mission plans for the first Orbiter, it showed the Subcommittee's direction of thinking:

The Planetology Subcommittee is disturbed that there are no scientific missions planned to take advantage of the unique capabilities of Lunar Orbiter for conducting investigations of the Moon, after the five flights in support of Apollo and Surveyor lunar landing site selection. In view of the opportunity to perform certain experiments (geodesy, gamma ray, x-ray, magnetometry, microwave, and non-imaging radar) in orbit about the Moon before the Apollo Applications Program, the Subcommittee recommends that every effort be made to undertake Lunar Orbiter scientific missions at the earliest possible date.34

The Subcommittee did recognize the priorities which placed Apollo and Surveyor requirements before any purely scientific objectives in the Lunar Orbiter Program and at its Spring 1966 meeting recommended "that major attention be given to photography of sites of scientific

33 Ibid., pp. 8-9.
34 Memorandum from SL/Chairman, Planetology Subcommittee (Dr. Urner Liddel) to SL/Director, Lunar and Planetary Programs, Subject: Resolution on Lunar Orbiter Scientific Missions, November 5, 1965.
interest, following the initial, successful Lunar Orbiter flight. These data are of particular importance in the planning and ultimate scientific value of both manned and unmanned lunar surface missions. 35

Mission planning activities continued to develop Lunar Orbiter's role in fulfilling Apollo and Surveyor requirements during the remainder of 1965 and the first quarter of 1966. It is necessary at this point to return to funding and hardware problems in the Lunar Orbiter Program because they comprise the other significant activity during 1965.

Funding and technical problems exerted significant influence upon the program's schedules. Already in April 1965 the total projected cost of the program was up by $10 million, of which $4.5 million was required in Fiscal Year 1965. Program Manager Scherer expressed surprise at this increase because NASA had been maintaining extremely close communications with Boeing. 36

The difficulty arose in communications between Boeing and the two major subcontractors: Eastman Kodak and RCA. The majority of the overrun was occurring in their operations. Eastman Kodak projected an increase of 26% in costs and RCA a 32% increase over original estimations. This situation reflected what NASA officials had suspected in January 1965. Boeing in its contract experience with the two companies had inadequate channels of communication. It was

35 Planetology Subcommittee of the Space Science Steering Committee, Meeting No. 4-66, May 9-11, 1966, p. 16.

mandatory that the cost overrun situation be corrected by vigorous cost reduction efforts among all participants. As things stood, Langley had $49.5 million for FY 1965, which meant that $5.8 million in unfilled orders would carry over into FY 1966.37

NASA management in charge of Lunar Orbiter realized that the funding situation might have been better if Eastman Kodak and RCA had agreed to the same type of incentive-fee contract as had Boeing. All major subcontractors could have been subject to the same incentives on a prorated share, NASA would have to implement stringent cost reduction efforts to maintain funding equilibrium. Moreover, Eastman Kodak and RCA already had been working under non-definitized contracts for a substantial period of time. This condition could have been avoided if the RFP had been more explicit.38

To combat surprise jumps in the expenditure rate NASA Headquarters directed Langley to conduct a specific cost reduction study, and Langley requested the same of Boeing. Both actions were initiated at the beginning of May. By May 4 the Lunar Orbiter Project Office had turned up 32 items where potential cost reduction might be possible. At the same time Langley and Boeing officials visited Eastman Kodak and RCA. Their purpose was to bring under control the costs of these two subcontractors, to prevent surprises such as the $10 million jump which had

37Ibid., p. 2.
38Ibid.
occurred in April, and to submit recommendations for cost saving items which would not affect schedules or disturb performance incentives.

Boeing officials conferred with Langley on May 11 and 12. The Vice Presidents of Boeing (Mr. Tewett) and RCA (Mr. Kruezer) attended. They informed Langley that Boeing was assigning one assistant project manager to RCA and Eastman Kodak each. These two officials would control changes and negotiations for changes and be completely cognizant of cost projections. Moreover, Boeing would send Langley and NASA Headquarters weekly cost projection statements. The assistant project managers assigned to RCA and Eastman Kodak were answerable directly to the Boeing Lunar Orbiter project manager.39

In addition to strengthening management, Boeing also submitted 53 specific items for cost reduction consideration. Scherer was pleased at the rapidity and extent of the Boeing probe for ways to cut costs. The 53 items totaled approximately $8.8 million, of which, by June, NASA had accepted over $4 million. There was still $1 million in items being reviewed for possible cost reduction. Some specific examples of major items deleted:

1. The program did away with the requirement to have the RCA test chamber as a back-up to the Boeing chamber in the testing phase. Amount saved -- $280,000.
2. The need and frequency for certain kinds of documentation was reduced, saving $40,000.
3. The redundancy of photo-receiving equipment at the Deep Space Instrumentation Facility sites was reduced, saving $250,000.
4. The need to perform burn-in on all parts

of the photo system at Eastman Kodak was altered to encompass burn-in of certain selected parts where this process had merit, further saving $350,000. 40

The decision to reduce by one the number of test spacecraft was a major change in program operations. As originally planned, Set C of components was to be built up into subassemblies for system testing. Following this, it was to become a complete spacecraft for systems design verification (SDV). Qualifications testing was to be performed with Spacecraft #1. Spacecraft #2 was to be used for mission simulation tests while Spacecraft #3 was scheduled for performance tests at the Goldstone site and for the integration tests at the Eastern Test Range at Cape Kennedy. The change would have the last two tests performed with the spacecraft built from the Set C components. Spacecraft #3 would be assembled according to the existing schedule. It would become a flight spacecraft unless required for testing. Should it be required for either of the last two tests, it would, nevertheless, be refurbished and used later as a flight spacecraft. Boeing agreed to this, making it possible to build one less spacecraft at a saving of $1.8 million. 41

NASA Program Manager Scherer felt that the entire cost reduction effort of April, May, and June had proved valuable for the program. The Lunar Orbiter schedule was very tight and events were moving fast. This effort had forced people to re-evaluate themselves, their procedures, and the requirements of their jobs and had generated

40 Ibid., pp. 1-2.
41 Ibid.
a new respect for cost effectiveness. Exactly how much would be saved in the long run was unpredictable, but Scherer believed that the impact of the cost reduction effort would certainly increase effectiveness in planning and management.

With the funding situation more firmly under control and the major testing programs advancing well, the moment of truth had arrived in the program. Would the first flight spacecraft meet its scheduled launch date in mid-1966? The Quarterly Review of mid-June at the Boeing Company in Seattle indicated optimistically that it would. Hardware problems were minimal, save for the line scan tube which caused a three-week schedule slip in the photo system. Boeing and NASA were completing required test and storage facilities on schedule while 28 of the 33 major Lunar Orbiter components were undergoing tests. Progress during July and August would decide whether the original first launch date could be met because the critical testing phase would tell if anything would have to be redesigned.

During the course of the summer months, while Mission A was being developed, further problems with hardware items darkened the horizon of Lunar Orbiter's progress. The propellant tanks of the velocity control engine were bursting during storage tests at the Bell Aero Systems Company, their manufacturer. The cause appeared to be stress corrosion of

\[42\] OSSA Review -- July 2, 1965 and July 30, 1965. By the end of July the problem with the line scan tube had been resolved. Excessive heat during sealing of the glass envelope had been causing damage to the drum bearing. This caused the motor to stall after a few hours of tests. A new tube was fabricated once the problem had been pinpointed, and it had successfully completed a 200 hour test. This affected the schedules of the ground spacecraft, but did not alter the schedules of the flight spacecraft.
the titanium alloy by the oxidizer. This complication necessitated a major meeting between Orbiter, Apollo, and Bell officials at North American, the prime contractor for Apollo, to review the history of the tanks. By September 9 Boeing was subjecting ten Bell tanks to tests in various configurations at Boeing to determine their safety margin for Orbiter applications. Following the tests Boeing sent the results to Bell. Meanwhile the OSSA Lunar and Planetary Programs Office requested the Office of Advanced Research and Technology to perform basic research to define the specific phenomenon causing the tanks to burst.\(^43\)

The tanks remained an unsolved problem despite the tests. The phenomenon responsible for their bursting could not be pinpointed quickly, and early in November the Lunar Orbiter Program Office reluctantly decided to install heavier, thicker-walled tanks with a weight penalty of six pounds.\(^44\) Fortunately this addition did not absorb the remaining weight margin for the spacecraft.

Progress was also hindered when Boeing Lunar Orbiter personnel discovered excess drift in the inertial reference unit (IRU) of one of the ground spacecraft. An investigation revealed dirty gyros. This caused an examination of all gyros for the IRU's in the remaining spacecraft, a task which would hold up completion of the guidance subsystem by thirty days. Boeing disassembled nine of the 29

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\(^44\) OSSA Review -- November 2, 1965, p. 2.
gyros which Sperry Rand, the fabricator, had delivered. All nine were found to be very contaminated. By the beginning of November Sperry had reworked four of the nine, but this was still insufficient if an impact on the schedules was to be avoided. Yet the time factor would be doubled if NASA decided to procure the gyros from another vendor, a fact which clearly revealed that Boeing and NASA were all but frozen to their present course.

These disturbing setbacks had not yet jeopardized the schedules, and progress on the whole was good. The major exception by November was the delivery of flight Spacecraft #3. Delays in the delivery of the photographic system had caused slippage in its delivery. By late October Lunar Orbiter management had narrowed the reason behind this to two items: the shutter for the 24-inch-lens camera and the Velocity-over-Height sensor. Both of these were being made by a subcontractor to Eastman Kodak: Bolsey Associates, Inc. Immediately the Langley Lunar Orbiter Project Office dispatched officials to visit the Bolsey plant. Their subsequent report criticized the firm's management.

Bolsey Associates, Inc., consisted of about 80 people running a small scale operation. The V/H sensor and the camera lens were the only two items which Bolsey had on a cost-plus-fixed-fee contract. Lunar Orbiter Program investigators found that Bolsey had absolutely no

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incentive to accomplish its work on time. Moreover, management of these critical items was very poor, and this had already affected the delivery of Spacecraft #3.\textsuperscript{47} This situation reflected bad coordination and control by Boeing and Eastman Kodak management, and NASA insisted upon major corrective actions. Subsequently Eastman Kodak assigned six full-time people to the Bolsey plant. The Lunar Orbiter Project Office followed this up with a complete schedule review on November 5 and another visit to Bolsey on November 10.

While Boeing and NASA Lunar Orbiter management took steps to improve the delivery schedule at the subcontractor level, Scherer's office was becoming more anxious about the total effect which the various hardware, management, and funding problems could have upon the incentive provisions of the Lunar Orbiter contract. In the original contract signed May 7, 1964, the target cost for the entire program had been $75,779,911. The target fee had been $4,736,244. The contract stated explicitly that "in no event shall the sum of the fee, adjusted pursuant to paragraphs (b) and (c) below, be more than fifteen percent (15\%) of target cost nor less than zero percent (0\%) of target cost."\textsuperscript{49} Paragraph (b) further stipulated how the actual cost was to be established and how the target fee was to be revised. Explicitly the contract

\textsuperscript{47} ibid.
\textsuperscript{48} ibid.
\textsuperscript{49} National Aeronautics and Space Administration Negotiated Contract No. NAS 1-3800, May 7, 1964, Part III. Fee Incentives, p. 1.
read: "(A) If the cost is equal to the target cost, the fee to be paid shall be the target fee. (B) If the cost is less than the target cost, the fee to be paid shall be increased by ten percent (10%) of the amount by which the cost is less than the target cost. (C) If the cost is greater than the target cost, the fee to be paid shall be decreased by ten percent (10%) of the amount by which the cost is greater than the target cost." 50

The crucial part of the Lunar Orbiter incentive-feee contract hinged upon the provisions defining the incentive. Two specific items determined the incentive: delivery and performance. An Evaluation Board composed of the Associate Administrator /of the NASA Office of Space Sciences, the Director of the Langley Research Center (or their nearest equivalents), and a chairman appointed by the Associate Administrator of NASA, would be responsible for evaluating the contractor's performance and delivery of the spacecraft in accordance with predetermined schedules. The contract stated that NASA would penalize the contractor "up to a maximum of $10,000 for each individual delivery date, for each calendar day, including Saturdays, Sundays, and holidays, by which actual accomplishment of delivery and acceptance shall have been later than the target date as set forth below. Spacecraft deliveries to the National Aeronautics and Space Administration will be effected in a sequential manner as follows:

<table>
<thead>
<tr>
<th>Flight Spacecraft No.</th>
<th>Delivery Date</th>
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<tbody>
<tr>
<td>1</td>
<td>May 7, 1966</td>
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50Ibid., p. 2.
<table>
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<tr>
<th>Flight Spacecraft No.</th>
<th>Delivery Date</th>
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<tr>
<td>2</td>
<td>May 7, 1966</td>
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<td>3</td>
<td>July 21, 1966</td>
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<td>4</td>
<td>October 21, 1966</td>
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<td>5</td>
<td>December 18, 1966</td>
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These provisions were tempered by two other stipulations which held the reduction in fee for any individual delivery to a maximum of $300,000, the equivalent of a delivery 30 days late. Moreover, the total penalty for all delays or late deliveries resulting from "causes beyond the control and without the fault or negligence of the Contractor as defined in Clause 12, Excusable Delays (September 1962), of the General Provisions attached hereto," were the responsibility of NASA.52

The history of the Lunar Orbiter Program until the last quarter of 1965 showed several constraints which possibly threatened delivery and over which Boeing had little or no control. The funding situation has previously been discussed as one of these constraints. Another one was the failure of NASA to couple delivery of ground spacecraft with flight spacecraft in the incentive provision of the contract. This had created an awkward situation by October which Scherer outlined in a memorandum to Clifford H. Nelson and Sherwood L. Butler at Langley. As certain hardware difficulties, the V/H sensor and the 24-inch-lens camera shutter for example, caused delays stretching into weeks, the testing programs for the ground spacecraft suffered. However, this did not hold up fabrication, testing, and delivery of the flight spacecraft because, as

51 Ibid.

52 Ibid., p. 3.
defined by the contract, the flight spacecraft could be delivered to NASA without the contractor having performed adequate prototype testing.

This meant that the delivery schedule incentive was in danger of losing any significance. In fact this parallel condition in the contract's structure which allowed flight spacecraft to be delivered without being contingent upon the development and testing of ground spacecraft, constituted a major loophole for Boeing, and Scherer urged that it be sealed off immediately.\(^5^3\)

Scherer also made it clear that when the time came for the three-man Evaluation Board to perform its tasks, the contractor would naturally be prepared to offer "the strongest possible justification of schedule delays based on government actions, such as late government furnished equipment or facilities and conflicts that will likely develop between Orbiter and other programs in the DSN."\(^5^4\) It was absolutely necessary for the Lunar Orbiter Program to substantiate the arguments of the Evaluation Board with verified documentary evidence pertaining to all aspects of the incentive provisions in the contract.

On April 20, 1965, representatives from Boeing, Lockheed, Langley, JPL, Lewis, and Goddard Launch Operations had met at Cape Kennedy for a major status review of the spacecraft and the preliminary mission plans. Boeing had presented its plans for using the Eastern Test Range

\(^5^3\) Memorandum from Manager, Lunar Orbiter Program, to Langley Research Center, Attention Mr. C. H. Nelson and Mr. S. L. Butler, October 28, 1965.

\(^5^4\) Ibid., p. 1. DSN = Deep Space Network.
facilities to conduct compatibility tests with a ground spacecraft. At this time it had also requested that it be allowed to evaluate checkout and operating procedures of ETR with the spacecraft's compliance with range requirements. This request necessitated the use of a launch vehicle which NASA's Lewis Research Center and Lockheed were to supply.  

NASA approved Boeing's request.

As part of this Boeing and Lockheed coordinated their efforts with the Goddard Launch Operations facility at Greenbelt, Maryland, to develop spacecraft flow data for Launch Complex 13 at Cape Kennedy. They completed this activity by May 10. NASA and Boeing further evaluated the requirements of the Deep Space Instrumentation Facility and the Space Flight Operations Facility which would be involved in Lunar Orbiter flight operations. On June 16 Boeing and Eastman Kodak officials met with personnel of the Deep Space Network to establish an interface with Eastman Kodak equipment. Once this was completed Boeing assisted the Deep Space Instrumentation Facility in the development of an activation plan for flight operations. The Deep Space Network was to concur on the plan before it could be implemented.

During the remainder of 1965 and the first half of 1966 major reviews in all areas of the Lunar Orbiter Program took place: spacecraft subsystems, testing and integration with launch facilities, testing and integration with data acquisition facilities, and compatibility with

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55 Boeing Quarterly Technical Progress Report, April to June 1965, Section IV, p. 64.

56 Ibid., pp. 65-66.
Apollo and Surveyor requirements. The Deep Space Network, meanwhile, had committed the Goldstone Echo site (DSIF 12) to the Lunar Orbiter Performance Demonstration Test throughout 1965. During this time Spacecraft "C" had undergone basic compatibility tests to check its systems design with the DSN.57

This left one thorny problem which threatened the completion of Lunar Orbiter testing at Goldstone. The Pioneer Mission A had placed a claim on Goldstone facilities which required that the DSN station provide "coverage of one pass per day for each of the first 30 days after launch." Moreover, Goldstone would track the Pioneer space probe on one pass per day for three days a week for the time period of launch plus 30 days to six months. This involved a substantial time factor which would impinge upon the Lunar Orbiter Performance Demonstration Test, still in progress.

The period from December 13, 1965, to February 3, 1966, had been designated by Boeing for the final testing phase. Once Spacecraft "C" had finished the Goldstone tests it would be shipped to Cape Kennedy for further tests in the Hangar 8 facility. As things stood the Pioneer launch threatened to delay Spacecraft "C" in the Goldstone tests, and this was something over which Boeing had no control. Thus a delay here would be charged to NASA's account in the final evaluation of whether the


58 Ibid.
contractor met the incentive requirements of the contract.

Kosofsky made the Flight Operation Working Group aware of the potential conflict and requested that it strive to minimize any delays in the Performance Demonstration Test. Some testing of the Lunar Orbiter at Hangar S could be conducted with Spacecraft #3, but it would lack the photographic system. However, the chief error causing the tie-up was overcommitment of the Deep Space Network's facilities. Marshall Johnson, DSN manager for Lunar Orbiter, attempted to rectify the situation before it could impact upon Lunar Orbiter schedules.59

While Johnson took action at the DSN to avoid schedule slippage, Scherer continued to prod Eastman Kodak and its subcontractor, Bolsey, to meet their schedule delivery dates. In a brief memorandum to Oran W. Nicks Scherer explained that he, Clifford Nelson, and Eugene Dralgy at Langley had conferred on the status of the EK/Bolsey situation. They had recommended that Thompson, Director of Langley, talk to management officials at Eastman Kodak by telephone rather than paying them a top level visit.60

In addition to Scherer's recommendation to Nicks, Homer E. Newell, Associate Administrator for Space Science and Applications, notified NASA Deputy Administrator Robert C. Seamans, Jr., about the schedule difficulties in the Lunar Orbiter Program on March 9 and asked that he release a telegram to the Boeing Company in an effort to bring the continual series of small schedule slips under control before they telescoped

59 Ibid., p. 2.
60 Memorandum from SL/Manager, Lunar Orbiter Program, to SL/Director, Lunar and Planetary Programs, March 7, 1966.
into a costly launch delay. The telegram, released by the Deputy Administrator on March 10, was addressed to Lysle Wood at Boeing. Showing top level concern at NASA Headquarters over the threatened status of the Lunar Orbiter schedules, it reads as follows:

The schedule of lunar orbiter is one of the highest priority to NASA. Both unmanned and manned lunar landing missions need the data to be obtained from successful lunar orbiter missions in order that our lunar exploration program can proceed as planned. Scheduled launch dates are requiring firm commitments for world wide network operations. Severe conflicts and delays may occur unless these launch dates can be adhered to.

In view of these facts I have become very concerned about the pattern of delays in deliveries of certain items for the orbiter, such as the photographic system and the inertial reference unit.

I want to emphasize the national importance of this program, the necessity for firm schedule adherence, and to inform you of my personal interest and concern in this matter. 61

Seamans indicated in his telegram to Boeing the kind of collision between various programs dependent upon the same facilities which delays could cause. Early in April further minor delays in deliveries of the photographic system occurred. There had been film alignment problems on the first flight-configured photo system. This caused a delay of one week. The V/H sensor in the first flight unit photo system had developed troubles which threatened to delay the delivery of this vital component until June 15. To compensate for this Boeing recommended that

61 Memorandum from S/Associate Administrator for Space Science and Applications to AD/Deputy Administrator, March 9, 1966, with telegram attached.
the V/H sensor from Spacecraft #2 be substituted on Spacecraft #4. This would ensure delivery of the first flight spacecraft by June 1. However, this change would reduce the time for mission simulation testing of the photo system on Spacecraft #2. Yet under the existing constraint of a July launch it was the best alternative. 62

Spacecraft #4, the first flight spacecraft, was undergoing matchmate with the adapter and the shroud at Boeing as of April 7. Boeing would subject it to vibration and thermal vacuum tests which it would complete by April 19. Then, if all went well, Boeing would ship it to NASA facilities at Cape Kennedy by May 10. Complementing this were two other items which had reached successful completion: software demonstration tests and inter-station compatibility tests. These activities led to the next major item on the schedule; formal mission simulation tests due to begin on April 11. 63

In the interim Leonard Reiffel of the Apollo Program notified Oran W. Nicks on April 4 that Apollo requirements for Lunar Orbiter data made it highly desirable, if not necessary, to have sufficient magnetic recording facilities to record incoming data on magnetic tape. He stated that quantitative photometric work made the use of magnetic tapes superior to film because "1. the quality of the data is degraded in the ground photographic process, and 2. magnetic tape provides higher


63 Ibid.
data processing convenience and speed.  

Reiffel emphasized the necessity to have back-up recorders to record all data and avoid irretrievable losses. If, however, this were not possible, he suggested that a tape change schedule be set up which would allow tapes on primary recorders to be changed during times when low resolution frames were being received at Deep Space Network facilities. Reiffel further requested a firm commitment on the availability of recorders including those for the first mission. He stressed that Apollo site selection analysis depended heavily on magnetically recorded data, and he requested more specific information on the Lunar Orbiter Program's plans for automatic data processing and validity tests of processed data.

Nicks answered Reiffel's memorandum on April 26. He concurred that a meeting between technical specialists from both programs should be

64 Memorandum from MA-6/L. Reiffel to SL/O. W. Nicks, Subject: Project Apollo Requirements for Lunar Orbiter Data, April 4, 1966. See also Bellcomm Technical Memorandum 65-1012-6, "Tape Recording of Lunar Orbiter Pictures," by C. J. Byrne, July 6, 1965. Recording on film of raw data transmitted by Lunar Orbiter presented certain limitations. First, film had a limited dynamic range and did not lend itself easily to enhancement. Secondly, it was much more difficult to computerize data from a film source than from magnetic tapes. Data recorded on tapes were the direct input signals from the spacecraft. This method of recording also eliminated any film processing errors and provided a greater dynamic range for analytical purposes. Once the tape-recorded data were computerized they could be enhanced by eliminating known and suspected interferences prior to reconstructing pictures of the lunar surface with such detail that slopes could be accurately determined within the constraints of Apollo requirements. Film-recorded data did not afford this flexibility.

65 Ibid.
called to discuss the problem of magnetic recording of data, the availability and cost of extra recorders, and the best way to secure Lunar Orbiter data in a form which the Apollo Program could utilize at the earliest possible date. However, he also pointed out that the Deep Space Network had received three FR 900 recorders but that their necessary amplifiers would not be delivered before June 1. This, the period of installation and testing, and the training of personnel to operate them mitigated against a firm commitment by the Lunar Orbiter Program for the first flight.

Nicks stated that the problem of back-up recorders had been investigated, and the results showed that the contractor, Ampex, could deliver three units by the end of October if an order were placed by May 15, 1966. The earliest date for their operation would be February 1, 1967, and the estimated cost would be about $600,000. Until the Lunar Orbiter Program had more reliable information on the performance of the FR 900 unit in the field, Nicks did not believe it was advisable to ask the Deep Space Network to purchase additional recorders. However, Boeing had been investigating the feasibility of changing tapes during reception of low resolution data, and it had indicated that this probably could be done.

One other area of major concern must be mentioned before further discussion of the final preparations for the first launch of a Lunar

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67 Ibid.
Orbiter spacecraft. This again concerns the NASA-Boeing contract and funding relationship. During March and April the Lunar Orbiter Program Office negotiated a new delivery incentive with the Boeing Company because of the necessity to move back the first launch date to mid-July. The new delivery date would be June 20, and this relieved some pressure from the timetable of events which schedule delays had caused. In addition NASA officials had taken the opportunity to correct previous weaknesses in the incentive clause of the contract.

Scherer reported to Nicks on April 7 that the Lunar Orbiter Program was close to meeting its obligations according to plan, but that accrued costs were about $10 million behind plan. The completion costs for RCA were estimated to end up one-half to one million dollars below the planned level. As if this were not sufficient to keep pressure on NASA and Boeing management, the machinist union at Boeing had failed to negotiate a new settlement with the company by the April 7 deadline, and a strike appeared unavoidable. If this were so, the union would have to call a strike before April 30, and the negotiations would be moved to Washington. Scherer indicated that this would impact upon Lunar Orbiter operations at Cape Kennedy. Despite this he could report that the program was still proceeding towards a tentative first launch date in July.

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68 Memorandum from SL/L. R. Scherer... , April 7, 1966, op. cit.
69 Ibid.
MISSIONS I, II, III: APOLLO SITE SEARCH AND VERIFICATION

NASA launched five Lunar Orbiter spacecraft to the Moon between August 1966 and August 1967, and all five successfully performed their missions. This set a precedent in NASA's lunar and planetary exploration. Not every Orbiter proved an unqualified success, but each one obtained valuable photographic data which has subsequently aided the Apollo Program in site selection for the manned lunar landing tentatively scheduled for July 1969. Moreover, Lunar Orbiter photographs enabled Surveyor Program personnel to verify landing sites and to place Surveyors in highly significant areas on the lunar surface to perform their assignments.

One major reason for the impressive record of five successful missions was the philosophy motivating the many individuals in the program. The men who had spent long months of preparation and training for the Lunar Orbiter flights had developed emergency procedures for almost any non-standard situation which might arise. In this way they avoided any potential catastrophe during a mission or squelched problems in their embryonic stage.

NASA and Boeing had designed Lunar Orbiter to be "tweaked." It was not launched and sent on its way to the Moon only to be left alone to perform its mission and expire. On the contrary NASA and Boeing built the spacecraft to operate in spite of certain inherent risks in each mission, in spite of potential failures in subsystems, and despite the external hazards of space. Built to function for a 30 day minimum
lifetime and an extended period of operation up to one year after the termination of the photographic mission, the five Lunar Orbiters proved very successful in fulfilling their mission requirements.

Five successful missions also proved the usefulness of the orbiter concept in unmanned lunar exploration and demonstrated its great potential for planetary exploration. Lunar Orbiter, unlike Ranger and Mariner, had the great advantage of being near its target for an extended period of time. If problems arose -- and they did -- the men on Earth could analyze them and prepare commands to the spacecraft to solve each dilemma. Although risk was a constant companion the Lunar Orbiters had a new dimension of flexibility once they were in orbit around the Moon. They were "forgiving" spacecraft because of the vastly extended time factor which allowed for compensation if a command were wrong or sent too early or too late.

Only 28 months from the time NASA Administrator James E. Webb had officially approved the program the first Lunar Orbiter was ready to begin its long journey to the Moon. A first mission success would reward the years of serious efforts in advancing lunar exploration, and it would open the door to new questions and greater challenges to America's technological abilities.

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1 Interview with Lee R. Scherer, Program Manager, at Cape Kennedy, July 31, 1967. This was part of a discussion between various members of the Lunar Orbiter Program including Clifford Nelson, Israel Taback, Thomas Young, Robert P. Bryson, and Martin Molloy at the home of Mrs. Mary Bub, a journalist, in Cocoa Beach, Florida.
Because of the launch of Surveyor I on May 31, 1966, and its need of the Deep Space Network and due to delays in the photo system for Lunar Orbiter I, the launch date for that spacecraft was finally scheduled for August 9. The Boeing-Lockheed-NASA team at the Eastern Test Range Launch Complex 13 and at the support facilities near Hangar S at Cape Kennedy counted the spacecraft down to T minus seven minutes. Then, with the launch only a short time away, an anomaly in the Atlas Propellant Utilization System caused a postponement of the mission until the launch window on the following day.²

Lunar Orbiter I, weighing 853 pounds, roared into space atop the Atlas-Agena D launch vehicle at 19:26 hours GMT on August 10. Launch operations personnel injected the Agena and the spacecraft into a parking orbit at 19:31 hours GMT, and at 20:04 hours the Agena injected Lunar Orbiter I into its translunar trajectory.³ All launch vehicle operations were executed without mishap. Lunar Orbiter I deployed its solar panels and antennas as planned and acquired the Sun on its yaw axis. The mission continued exactly according to the preflight plan until the time of the initial acquisition of the star Canopus.⁴

The Canopus star tracker sensor proved to be one of two major problems during the Earth-Moon transit of the spacecraft. On August 11 at

²Boeing Quarterly Technical Progress Report, Lunar Orbiter Program, July to September 1966, Section IV, p. 35.
³Ibid., p. 36.
02:14:57 hours GMT the ground control at the Jet Propulsion Laboratory commanded the Canopus sensor to turn on. At this time it indicated excess voltage 1 1/2 times more than the preflight calculated signal voltage. Acquisition of Canopus failed. The probable reason for this was that the sensor was responding to excess light reflected from some part of the spacecraft's structure. In the following hours Lunar Orbiter ground control at JPL attempted a number of tests and experiments to correct the anomaly or circumvent it. By 13:50 hours on August 13 an initial Canopus lock was achieved but subsequently lost.5

The necessity for an attitude-stabilized spacecraft such as Lunar Orbiter to acquire proper stabilization in reference to the Sun, the Moon, and the star Canopus cannot be overstressed. Unlike a spin-stabilized spacecraft Lunar Orbiter I depended upon proper orientation along its yaw, pitch, and roll axes to arrive in the vicinity of the Moon in the proper position to be injected into lunar orbit. Thus the difficulties which the Canopus sensor was creating potentially threatened the mission. After the first lock was gained and lost and mission control knew that the sensor was operating properly, it developed a technique which used the Canopus sensor during periods of occultation of the Sun to verify or correct the orientation of Lunar Orbiter I.6

The other major problem during the cislunar transit was overheating of the spacecraft. This did not become serious until after the mid-

5Ibid.
6Ibid.
course maneuver. To perform this maneuver despite the trouble with the Canopus sensor Lunar Orbiter ground control used the Moon instead of Canopus as the roll reference. The midcourse burn was executed to orient the spacecraft 36 degrees off-Sun. This attitude was maintained for 8.5 hours. The purpose of the maneuver was to lower the temperature of the spacecraft equipment mounting deck during transit. The coating on the exterior of the deck was degrading under solar radiation at the expected rate, and no acute overheating was experienced until Lunar Orbiter I was already in orbit around the Moon. Nevertheless, the planned heat dissipation period when the spacecraft was flown 36 degrees off-Sun did not seem to retard overall degradation of the thermal coating on the exterior of the equipment deck.

Lunar Orbiter I began the sequence of events placing it in orbit around the Moon at 15:22:56 hours GMT on August 14. It executed another thermal relief maneuver which lasted 7.5 hours prior to final orbit injection. This provided optimum temperature conditions before the critical insertion into lunar orbit. The final injection sequence elapsed without any trouble, and Lunar Orbiter I was ready to begin the major work of its mission.

The photographic mission of Lunar Orbiter I was entirely Apollo-oriented. Once the spacecraft had been placed in its initial orbit

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7 Ibid., p. 7.
8 Ibid., p. 8. See also Boeing Quarterly Technical Progress Report, op. cit., p. 36.
9 Interview with G. Calvin Broome, Langley Research Center, July 19, 1967.
with an apolune of 1866.8 kilometers and a perilune of 189.1 kilometers. Ground control checked out its systems. The necessity to fly off-Sun and the excess number of maneuvers required because of the Canopus sensor had affected the interrelationships between the spacecraft's systems, and ground control had to make compensations for this, especially with the power system so that the batteries would not be overtaxed.

On August 15 during the sixth orbit ground control successfully commanded Lunar Orbiter I to read out the Goldstone Test Film which had been loaded into the photo system prior to launch. This film was designed to test the readout system and to gauge the quality of subsequent photographs. 10

At the time of the Goldstone Test Film readout the thermal problem became acute. The coating on the exterior of the equipment deck was supposed to radiate excess heat during periods of solar occultation. It did this approximately as predicted, but heat levels continued to rise. This was probably due to more rapid degradation in the pigment of the coating than had been expected. However, on August 18 during the 20th orbit a power transistor in the shunt regulator array failed, and this had a compensating effect on battery temperatures. It placed an extra load of 1.2 to 1.5 amperes on the power system, which increased the battery discharge rate during occultation of the Sun. Secondly this extra load meant that the off-Sun angle of 36 degrees could be reduced slightly at the time when sufficient power for readout was re-

quired of the power system. 11

After orbiting the Moon for four days and twenty-three hours Lunar Orbiter I began the first operation of its photo system since the readout of the Goldstone Test Film. Eleven frames were advanced and processed during the 25th orbit at 12:12:13.06 hours GMT on August 18. This brought active film into position for the first photographic sequence to commence on orbit 26. Subsequently the cameras exposed 20 frames over Site I-0 the Mare Smythii. 12 The photography appeared to be nominal.

Ground control commanded the spacecraft to open the thermal door covering the camera. Two photo sequences were then executed: one of 16 and one of 4 high and medium resolution exposures. They were made at an altitude of about 133 nautical miles above the Moon while the velocity of the spacecraft was about 4,000 miles per hour. Exposure time for each camera shutter was 1/50 of a second, and simultaneous medium and high resolution pictures were made every 2.5 seconds. After this the thermal door was closed, and the film underwent processing. 13 Five hours later the readout process began at 19:50:42 hours GMT on August 18. Ground control commanded the pictures of Site I-0 to be read out four times. All the medium resolution frames were excellent in quality and so was the first high resolution frame. However, the other

11 Ibid., p. 9.

12 Ibid.

13 Lunar Orbiter I Mission Status Report 8, Status as of 11:30 a.m. EDT, August 18, 1966.
four high resolution frames showed severe image smearing. Lunar Orbiter ground control personnel estimated that the shutter of the 610 mm lens camera was out of synchronization with the V/H sensor, and further investigation revealed this to be the case. 14

To verify the cause of the high resolution smearing, flight operators in charge of photography quickly designed a test of the 610 mm camera's focal plane shutter. After completion of the Site I-0 photography ten more exposures were made for purposes of diagnosing the problem. The exposure rates were varied with and without the V/H sensor turned on. Then another test was conducted to determine if the V/H sensor was the cause of the smearing. Three steps were taken:

1) Camera thermal door was opened and the V/H sensor was turned on;

2) The sensor was left on for approximately 2 minutes and then turned off;

3) The camera thermal door was then closed and the camera shutter was commanded to take a picture with the door closed and to move fresh film into the camera for the next photograph. 15

The tests confirmed that the abnormal operation occurred when the V/H sensor was on because a high resolution exposure was made with the thermal door open while no medium resolution exposure was taken. Despite this flight controllers made no deviations from the flight plan, and the spacecraft was transferred to its lower, final orbit

14 Lunar Orbiter I Mission Status Report 9, Status as of 9 a. m. EDT, August 19, 1966.

at 09:49:58.7 hours GMT on August 21. The new orbital parameters were: 1,855 kilometers apolune, 58 kilometers perilune, inclination to the lunar equator was 12.32 degrees. At this lower altitude the V/H sensor would generate a higher output voltage above any noise level. Ground control believed that this would improve the shutter's performance.

Just prior to the lower orbit transfer Lunar Orbiter I took two frames of medium and high resolution pictures of the Moon's farside at an altitude of 1,497 kilometers. The V/H sensor was off, and after the frames were read they revealed high quality pictures in both medium and high resolution of the lunar surface without smearing.

Another problem occurred prior to final orbit transfer which required the photo system to take unplanned additional pictures. The Bimat was apparently sticking. The original plan called for fresh Bimat to be placed on the processing drum at least every 15 hours. This would meant that two frames/be processed every four orbits. However, evidence of Bimat stick in the early frames precipitated the decision to use additional film which would permit processing during every orbit. Eight extra pictures were to be taken. This and the extra diagnostic

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17 Lunar Orbiter I Mission Status Report 11, Status as of 8:30 a.m. EDT, August 22, 1966.
pictures taken to help evaluate the high resolution shutter problem forced a revision in the planned photographic coverage of the remaining sites. The result was that only eight exposures would be taken of Sites 4, 6, and 8, while the other sites would receive the original 16-frame coverage.21

The trouble in the high resolution shutter continued to plague photography when the V/H sensor was operating despite the increase in output voltage. Further analysis of the problem revealed that the logic control circuitry of the 610 mm camera's focal plane shutter was susceptible to electromagnetic interferences. This made it impossible to solve the problem by modifying procedures, and low altitude high resolution photography on the first mission proved a failure.

Nitrogen gas, used by the attitude control system to maneuver the spacecraft, had been expended in greater amounts than originally planned because of the difficulties in the Canopus star tracker and in the alterations of planned photography caused by the problems in the high resolution shutter and the evidence of Bimat stick. Moreover, thermal relief maneuvers and excess attitude update maneuvers, together with the failure of a gas regulator, increased the rate of nitrogen usage. Between August 23 and 31 an average of 0.375 pounds of nitrogen was expended per day. Flight controllers implemented an economizing procedure: they commanded the spacecraft to fly off-Sun on its pitch axis, update its attitude on the pitch and yaw axes using the coarse Sun sensors, and on its roll axis

21Ibid.
using the Canopus sensor. This resulted in an expenditure of 0.09 pounds per day between September 1 and 14.  

From the final orbit perilune of 58 kilometers Lunar Orbiter I was deboosted successfully to a record low altitude of 40.5 kilometers for further photography on August 25. This move was the result of an analysis of the V/H sensor in a duplicate Lunar Orbiter photo system on the ground by Eastman Kodak engineers on August 24. They had concluded that the V/H sensor would operate nominally below an altitude of 51 kilometers. In the new, lower orbit smearing of high resolution photographs was reduced somewhat by increasing the shutter speed from 1/50 to 1/100 of a second. Better lighting conditions made this possible. But smearing never completely disappeared from high resolution photographs, probably because of transient arcing in shutter control circuitry.

By August 29 Lunar Orbiter I completed its photographic acquisition with a total of 205 exposed frames. Thirty-eight of these had been taken in the initial orbit; 167 were made in the lower final orbits. The spacecraft successfully photographed all nine potential Apollo landing sites. Pictures of eleven sites on the backside of the Moon and two Earth-Moon pictures were taken. Readout of the photographs began on August 30 at about 4:30 p. m. EDT.

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23Lunar Orbiter I Mission Status Report 14, Status as of 9 a. m. EDT, August 24, 1966.
24Lunar Orbiter I Mission Status Report 18, Status as of 10 a. m. EDT, August 29, 1966.
25Lunar Orbiter I Mission Status Report 20, Status as of 11 a. m. EDT, September 1, 1966.
Of all the pictures which Lunar Orbiter I made, none was so spectacular or won so much world-wide recognition as the first photograph of the Earth taken from the vicinity of the Moon. To take the picture it had been necessary to maneuver the spacecraft to look away from the lunar surface. Because this was an unplanned photo, coming early in the mission, Boeing Company management hesitated to commit the spacecraft to such a hazardous, unnecessary task. NASA program manager Scherer, together with Leon Kosofsky, the program engineer, Martin T. Swetnick, the program scientist, and Clifford Nelson, the project manager, conferred with Boeing personnel several times and convinced them that the picture was worth the risk. After agreement had been reached, Lunar Orbiter ground control executed the necessary maneuvers to turn the spacecraft's cameras away from the lunar surface, and the spacecraft took two spectacular and very useful pictures.

The Earth-Moon shots proved valuable for their oblique perspective of the lunar surface. Until these photographs all pictures had been taken from a vertical or near-vertical position perpendicular to the Moon's surface. On subsequent Lunar Orbiter missions oblique photography was planned and executed more and more. (See the photographs in the Photographic Folio.)

Lunar Orbiter I began its extended mission on September 16 after completion of photographic readout. During this extended time period

Lunar Orbiter engineers and scientists tracked the spacecraft at regular, planned intervals to acquire selenodetic data and monitor the spacecraft's behavior in the lunar gravitational field. Secondly they monitored the micrometeoroid sensors to detect the frequency of micrometeoroid hits in lunar orbit over a longer period of time than 30 days.

By October 28 the situation of Lunar Orbiter I had deteriorated significantly. Scherer issued a status report which pointed out the following: 1) very little gas remained for attitude control (0.9 pounds at 100 p.s.i.); 2) estimated stabilized life of the spacecraft was two to five weeks; 3) The battery was losing power because of prolonged overheating, and if it fell below 15 volts, the on-board programmer would lose essential parts of its memory; 4) The transponder was responding erratically, and the inertial reference unit was losing its ability to keep the spacecraft stable. The program manager and his staff realized also that loss of control over Orbiter I could jeopardize the mission of the second Lunar Orbiter. They decided, therefore, to command the spacecraft to impact on the far side of the Moon during its 577th orbit at 0930 hours EDT on October 29. This maneuver was successfully executed, bringing to an end the first mission.

Lunar Orbiter I photography was subjected to numerous analyses, photometric enhancement processes, and evaluations by technicians and

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scientists at the Langley Research Center. Langley also began distributing photographic data for more detailed investigation by Eugene Shoemaker and his staff at the U. S. Geological Survey. The U. S. Army Map Service, along with the U. S. Air Force's Aeronautical Chart and Information Center, and NASA further evaluated the lunar photography with particular attention to lunar mapping and Apollo requirements. One immediate objective of these various analyses was the application of these photographic data in the planning of the second Lunar Orbiter mission.28

Some of the most significant problems which the first mission photography revealed were the following: 1) photographic imperfections due to mechanical operation in the photo system (for example, partial because of dry out of the Bimat /pressure variation of a roller in the processor mechanism produced a narrow strip of incorrectly processed film ); caused by 2) density variations /the GRE kinescope tubes; 3) smear of high resolution photographs /improper V/H sensor operation, which has been previously discussed.29

The second Lunar Orbiter mission ran into difficulties during May 1966, six months before the tentative launch of Lunar Orbiter II. On May 20 NASA and Boeing program officials conducted a preshipment review of Spacecraft #5 at the Boeing Company. This spacecraft was to serve as a backup for the first mission and was to be launched on the second


mission in the event of a success on mission one. After reviewing the history of Spacecraft #5 NASA’s review team refused permission to ship it to the Cape Kennedy facilities without further testing. The Boeing Lunar Orbiter program officials objected strongly to this, but the history of Spacecraft #5 revealed a need to overcome inadequate operations of important equipment.

Having been subjected to the same tests as Spacecraft #4 (Lunar Orbiter I), Spacecraft #5 was considered ready for shipment with one major exception. The camera thermal door had failed to open during thermal vacuum testing. The other thermal vacuum tests were completed, save this one. Again it was attempted. The thermal vacuum chamber was pressurized and the command was sent for the door to open. Again it remained closed. Next the monitor operations were observed and after some of the thermal barrier had been pulled loose the door operated correctly through several cycles. Following this the door and its motor mechanisms were removed from the spacecraft for special thermal vacuum tests.

The Boeing Company officials wanted the spacecraft shipped to Cape Kennedy without the door while the door underwent further tests. Once the cause of failure was isolated it could be corrected, and the door could be reinstalled at the Cape. NASA officials vetoed this sugges-


31 Ibid.
tion because of a long history of development troubles with the door mechanism. Nevertheless Boeing officials threatened to ship the spacecraft anyway, claiming that they would merely be effecting a transfer from Boeing Seattle to Boeing Florida. Their major reason for this was the delivery deadline for a second flight spacecraft of June 22. NASA Lunar Orbiter officials disagreed with this line of reasoning and insisted that the facts were evident. The spacecraft had failed a specified test. It was necessary to retest the whole spacecraft. Boeing reluctantly accepted this verdict, and issued instructions to return the spacecraft to the test chamber. This decision ended the lengthy review at 1:15 a.m. on May 21.\(^{32}\)

While Boeing reworked the camera thermal door, the Lunar Orbiter Program and Project Offices continued to formulate plans for the second mission. Original planning for Mission B had only photographic data from Earth-based telescopes and Ranger spacecraft to rely upon because Lunar Orbiter I had not yet flown. On May 6, 1966, representatives from Bellcomm, the Apollo, and the Surveyor Programs met with Lunar Orbiter Program officials at Langley for the Mission B Planning Meeting. The information and requests which they provided resulted in the following guidelines for Lunar Orbiter Mission B:

1. Distributed sampling with a string of sites located in the northern part of the Apollo zone.

2. Sample both mare and highlands with greatest number of samples in the mare.

3. Sites spaced consistent with the lighting at LEM landing constraints. (Present value of sun elevation of 7 to 20

\(^{32}\)Ibid., p. 3.
degrees will be used -- results in optimum spacing equaling 11 degrees, plus or minus 2 degrees.)

4. One of the mare sites to be the Ranger 8 impact point.

5. The availability of a landed Surveyor and/or any new data will necessitate a review of any mission design.

6. Mission B sites shall be selected such that an inspection of the terrain to the east appears to be consistent with the Apollo landing approach constraint, where possible. 33

The members of the several organizations at the meeting produced a Mission B plan which the Lunar Orbiter Program Office presented to the Surveyor/Orbiter Utilization Committee on June 1. The plan had three primary goals based upon Ranger and Earth telescope data and performance evaluations of the Lunar Orbiter spacecraft systems:

A. Photographic - To obtain detailed lunar topographic and geologic information of various lunar areas to assess their suitability for use as Apollo landing sites.

B. Selenodetic - To provide trajectory information which will improve the definition of the lunar gravitational field.

C. Environmental - To provide measurements of micrometeoroid and radiation flux in the lunar environment for spacecraft performance analysis. 34

Apollo requirements had priority as on the first mission. The area to be covered was a swath along the front side of the Moon ranging between +5 and -5 degrees latitude and +45 and -45 degrees longitude.

33 Minutes of the Lunar Orbiter Mission B Planning Meeting, Langley Research Center, May 6, 1966 (recorded by A. Thomas Young), pp. 5-6.

34 Lunar Orbiter Mission B Description, Lunar Orbiter Project Office, Langley Research Center, June 1, 1966.
Topographic considerations affecting the mission plan dictated that Lunar Orbiter B (Lunar Orbiter II) look for areas smooth enough for the Apollo Lunar Module to land on. The approaches to these areas had to be free of obstacles over a certain height to allow satisfactory performance of the Lunar Module landing radar.\textsuperscript{35}

The Lunar Orbiter Program and Project Offices agreed upon eleven sites to be photographed. The spacecraft would execute a minimum number of maneuvers to keep the mission simple. There would be one photographic pass per site, and high orbit photography would be eliminated. Lunar Orbiter II would carry out contiguous high resolution vertical photographic coverage between adjacent orbits. This called for an inclination of $11^\circ$ to $12^\circ$. Surface lighting conditions had to be such that photography could detect cones of two meters diameter and $\frac{1}{2}$ meter height and slopes of $7^\circ$ in an area of seven meters square.\textsuperscript{36}

On September 29 the tentative Mission B plan was amended. The photography and spacecraft performance evaluations of Lunar Orbiter I, in addition to further inputs from Bellcomm, the U. S. Geological Survey, the NASA Houston Manned Spacecraft Center, NASA Headquarters Office of Manned Space Flight, and the Surveyor Project Office confirmed tentative mission objectives for the second Lunar Orbiter flight more than they altered them. As of October 26 the objectives were:

\textsuperscript{35}Ibid., p. 7.
\textsuperscript{36}Ibid., p. 12.
Primary -- To obtain, from lunar orbit, detailed photographic information of various lunar areas, to assess their suitability as landing sites for Apollo and Surveyor spacecraft, and to improve our knowledge of the Moon.

Secondary -- To provide precision trajectory information for use in improving the definition of the lunar gravitational field.

To provide measurements of micrometeoroid flux and radiation dose in the lunar environment, primarily for spacecraft performance analysis.37

During the process of site selection for the second Orbiter mission a hypothesis based upon Earth telescope and Ranger VII pictures exerted a particular influence on the choice of sites. Data from these two earlier sources tended to show that bright rays extending from younger craters were actually heavily cratered, making landings very hazardous or impossible. To test this Lunar Orbiter I had photographed sections in lightly rayed areas. Specifically, photographs of Site A-3 in Mare Tranquillitatis revealed smooth areas where a Lunar Module could land. Orbiter I Frame M-100 of Site A-3 shows an area in a light ray where cratering is not sufficient to rule it out as a landing site. The ray in this photograph is faint and probably has its origins in the crater Theophilus but has subsequently been filled in.38


38Discussion with Dennis B. James, Bellcomm, Inc., July 25 and 28, 1969. The author and Mr. James studied photographs of Site A-3 and Frame M-100, at which time Mr. James pointed out the significances of these pictures. These photographs are located in the Bellcomm files.
Planners concluded from Orbiter I photography that some ray areas were possibly very smooth. Moreover, some photography from the first Orbiter had actually previewed certain targets in the B Mission. Thus planners decided to change several sites in the second mission and to have Lunar Orbiter II look at the ray areas between Copernicus and Kepler, extending north of the western Apollo zone. Mission B and Mission II thus were substantially different as a result of the divergences between Ranger VII and Orbiter I photographs of crater rays. 39

Less than three months elapsed between the launch of the first Orbiter and that of Lunar Orbiter II. On November 6, 1966, this second spacecraft began its journey to the Moon at 23:31 hours GMT. The cis-lunar transit went as planned with no trouble in the Canopus star tracker. A small midcourse correction was made approximately 40 hours after launch, and the initial orbit was established approximately 90 hours into the mission. 40 The first orbital parameters were 1350 kilometers apolune and 200 kilometers perilune. Nominal photographic altitude was 45 kilometers with the spacecraft inclined 12° to the lunar equator. 41

At 22:58 hours GMT on November 15 Lunar Orbiter II went into its

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40 Boeing Quarterly Technical Progress Report, October to December, 1966, p. 5.

final orbit configuration: apolune -- 1350 kilometers, perilune -- 42 kilometers. On November 18 it commenced its photographic work. The photo system performed very well during all phases of the mission and covered each of 13 primary and 17 secondary sites as planned. Only Secondary Site II S-10.2 was replanned during the mission to avoid operating the spacecraft on batteries, a procedure which would violate a design restriction. Several changes were made in the photo system of Lunar Orbiter II as a result of the first Orbiter mission:

1. The addition of an integrating circuit in the focal-plane shutter control circuits to ensure that an output signal represents a valid command pulse (containing amplitude and duration) and not the result of an electrical transient.

2. The addition of a filter on the 29-volt line to minimize electromagnetic interference and possible triggering of photo subsystem circuits.

3. The platen clamping spring tension was increased to ensure immobility of the film during exposure, improve the film flatness, and maintain focus.

4. Reseau marks were pre-exposed on the spacecraft film in a specific pattern to assist in compensating for any non-linearities in the optical-mechanical scanner.

The medium and high resolution photography was excellent in quality and indicated that the operation of the photo system during exposure, processing, and readout was very good.

On November 20 Lunar Orbiter II photographed the impact point of


Ranger VIII (Site II P-5). On November 23 it recorded the most spectacular picture ever taken of the lunar surface. The threat of Bimat stick required the movement of new film and Bimat onto the processor drum at regular intervals. This meant planned waste of film if no exposures were made. Program officials decided, however, to have the spacecraft photograph the crater Copernicus when it passed 150 miles due south at an altitude of 28.4 miles (45 kilometers) above the Moon. The 610 mm high-resolution camera made a dramatic exposure of the crater from a long, low oblique angle. It revealed to earthbound scientists geographic and topographic features of the central portion of this 60-mile-wide crater never before recorded. Dominating the center of the picture are mountains rising 1,000 feet from the crater's floor. Behind them is a ledge of bedrock and the crater's rim. Behind all of this stands the Gay-Lussac Promontory in the Carpathian Mountains, towering 3,000 feet above the lunar surface on the horizon. (See photographs in the Appendices.)

This and the oblique shots of Marius and Reiner Gamma proved to be of extremely high value to the photogrammetrists, astrogeologists, and other scientists connected with the Lunar Orbiter Program. The nation's news media described the Copernicus shot as "one of the great pictures of the century." 45

Lunar Orbiter II ended its photographic acquisition on November 26, and ground control concluded the readout on December 7. Only one set-back marred an otherwise unqualified success. The traveling-wave-tube amplifier (TWTA) failed on the final day of the photographic readout, and half of the photographs of the secondary Site II S-1 were not obtained. This area was located at 41.1° east longitude and 3.2° north latitude in Mare Tranquillitatis. However, priority readout of the wide-angle photo coverage of this site had previously been conducted, reducing the seriousness of the TWTA failure.

The spacecraft recorded three known micrometeoroid impacts during a 19 day period of the mission. These hits did not affect the performance of the spacecraft. Lunar Orbiter I had registered no hits, and program scientists believed the Lunar Orbiter II hits may have been from the annual Leonid shower.

Lunar Orbiter II demonstrated its ability to obtain high quality oblique photographs of the near and far side of the Moon. It also obtained excellent convergent stereo telephoto pictures of selected sites. Moreover, it showed that not all light rays were necessarily heavily cratered but that the Copernicus-Kepler region was unfit for landing sites. These achievements attested to the accuracy and precision with

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47 Ibid., p. 86.
which the ground control was able to position the spacecraft for photographing specific objectives. Which the ground control was able to position the spacecraft for photographing specific objectives. Finally the problem of overheating which had made excess necessary maneuvers during the mission of Lunar Orbiter I was overcome on the second mission. With the addition of a coating of S-13G, degradation of the thermal paint on the equipment deck of Lunar Orbiter II was substantially reduced. Thermal control of the spacecraft by planned thermal relief maneuvers was better integrated into the total flight operations plan for the second mission, and the spacecraft performance proved markedly better than that of the first Lunar Orbiter mission.

The third Orbiter mission differed slightly from the first two because it concentrated its photography on Apollo and Surveyor site confirmation instead of mere verification. The convergent stereo photography of Mission II had proved successful and highly useful to the Apollo and Surveyor Programs. It consisted of making two "footprints" of the same area on two successive orbits. The first photographic exposure was taken in a tilted sequence to the target. Resolution of a convergent stereo picture was slightly degraded by the necessity to tilt the camera on one of the two passes. Degradation was from one meter to $2\frac{1}{2}$ or 3 meters in resolution.

The Aeronautical Chart and Information Center (ACIC) evaluated the Mission II convergent stereo photography and concluded that "this type of photography increases the topographic knowledge that can be obtained

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48 Ibid.
49 Ibid.
concerning potential landing sites." The Lunar Orbiter Program Office planned to include more convergent stereo coverage on Mission III as a result of the ACIC evaluation. During the second Orbiter mission stereoscopic photography (convergent stereo mode) of Site II S-2 had revealed that good quality high resolution photos permitted direct stereoscopic slope measurement. As a contingency measure in the event of the failure of the medium resolution camera extensive stereo photography had been planned for the 610 mm camera.

On November 15, 1966, a technical interchange meeting convened at the Jet Propulsion Laboratory to assess the various methods of calibration of Lunar Orbiter's high resolution camera. Precise geometric calibration was mandatory if convergent stereo photography were to be conducted successfully on the three remaining missions. Calibration was to be done at the photographic system level, and the members of the meeting determined which method of calibration to use. Leon Kosofsky, the Program Engineer, coordinated the activities involved in calibration.

On January 5, 1967, the Ad Hoc Surveyor/Orbiter Utilization Committee of the Office of Space Science and Applications approved the plan for the third Lunar Orbiter mission:

Mission III is primarily designed to photograph promising areas that have been identified by screening Lunar Orbiter I and II photographs and for which additional data is

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needed to confirm their adequacy as Apollo and/or Surveyor landing sites. In addition Mission III will provide photography of broad scientific interest as did Missions I and II. 52

The mission would also obtain precision trajectory information to be used in improving the definition of the lunar gravitational field, measurements of micrometeoroid flux and of radiation levels in near-lunar environment for use in evaluating spacecraft performance. Finally Lunar Orbiter III would serve as a target for the Manned Space Flight tracking stations that they might use and evaluate the Apollo tracking network and the Orbit Determination Program. 53

The Launch Readiness Review for Lunar Orbiter III (Spacecraft #6) and for the back-up Spacecraft #7 was held at the Eastern Test Range facilities on January 17, 1967. Both Orbiters were found to be ready for launch, and personnel working with Spacecraft #6 proceeded with preparations for that event. Boeing and Eastman Kodak were resolving the problems which had caused minor film processing defects on the first two missions. Manufacturing anomalies and bubbles in the Bimat had been the chief cause of these defects. Still unresolved was the failure of the TWTA on Lunar Orbiter II. However, Boeing engineers were modifying this component so that excess heat buildup could be vented off, prolonging the lifetime of the tube. Readout times would also be reduced in the event of heat buildup and ground


control would monitor the helix current since program scientists considered any irregularities in its flow as an indication of pending trouble in the TWTA.  

All problems resolved, Lunar Orbiter III lifted off of Pad 13 at the Eastern Test Range at 01:17 hours GMT on February 5, 1967, for its 90 hour voyage to the Moon. Launch and injection went as planned, and seven hours into the mission ground control commanded Lunar Orbiter III to turn on its Canopus star tracker and give a star map prior to Canopus acquisition. It executed this command successfully. On Monday, February 6, at T plus 37 hours the Space Flight Operations Facility tracking Lunar Orbiter III commanded a midcourse correction maneuver to adjust the spacecraft's cislunar transit, and the maneuver was so accurate that no second midcourse was required.  

At 4:54 p.m. February 8 America's third Lunar Orbiter fired its 100-pound-thrust rocket engine for 9 minutes 2.5 seconds to deboost the spacecraft into its initial orbit. The parameters were: apolune -- 1,801.9 kilometers, perilune -- 210.22 kilometers, inclination 20.93°, period 3 hours 35 minutes. After four days in this orbit during which ground control monitored the spacecraft's systems, it was transferred into a final orbit. The new apolune was 1,847 kilometers, the

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54 Memorandum from SL/Manager, Lunar Orbiter Program to SE/Deputy Associate Administrator for Space Science and Applications (Engineering), January 24, 1967.

55 Boeing Quarterly Technical Progress Report, January to March, 1967, p. 4. See also Status of Lunar Orbiter III (as of 8 a. m. EST, February 7, 1967).

56 Status of Lunar Orbiter III, February 9, 1967, p. 3.
perilune 55 kilometers. Inclination was 20.9 degrees.\textsuperscript{57}

As \textit{Lunar Orbiter III} had executed its deboost maneuver \textit{Lunar Orbiter II} was still in orbit on the far side of the Moon. On February 6 ground control began tracking both spacecraft. It tracked \textit{Lunar Orbiter II} for one hour and demonstrated its ability to track the two spacecraft in orbit around the Moon at the same time. This exercise greatly extended the usefulness of each mission by providing simultaneous telemetry on two orbiting spacecraft. Monitoring showed that all \textit{Lunar Orbiter II} systems were functioning nominally.\textsuperscript{58}

\textit{Lunar Orbiter III} began its photographic mission on February 15 over the primary Site III P-1 at 35 degrees 15 minutes east longitude, 2 degrees 55 minutes north latitude, near Maskelyne F in the southeastern region of Mare Tranquillitatis. The first readout in the priority mode revealed photographs of excellent quality. A Class IV solar flare which occurred at 12:54 p.m. EST on February 13 exhibited high optical activity, but there was little proton activity and therefore a minimal threat to the film onboard \textit{Lunar Orbiter III}.\textsuperscript{59} First readout revealed no fogging of the film and indicated that all systems were working normally.

The film advance mechanism in the readout section of the photo


\textsuperscript{59}Status of Lunar Orbiter III (as of 3:30 p.m. EST, February 13, 1967 and Status of Lunar Orbiter III, February 16, 1967.
system of Lunar Orbiter III began to show erratic behavior even during the mission's photographic phase. Because of this the Program Manager and his staff decided to begin final readout earlier than planned.

Ground control at JPL commanded the spacecraft not to photograph secondary Site S-32, an oblique shot of the Grimaldi area. A total of 211 out of 212 planned frames had been exposed when, at 1:36 a.m. EST, on February 23, ground control commanded the spacecraft to cut the Bimat. This closed the photographic portion of the third mission. By March 1 readout had acquired of 114 frames of photography or 54% of the total. Film advance through the readout gate was intermittently hampered during this time, but no loss of photography had been suffered.

Then suddenly on March 4 readout ceased. Seventy-two of the 211 frames still remained to be read out, but the worst had happened. The film advance motor, which had been showing signs of abnormal performance, had burned out, and the 72 frames remained on the readout looper. Program engineers estimated that an inexplicable electrical transient had fouled up the photo system's logic, causing the motor to run out of control. Nonetheless, 70% of the photographic data had been transmitted to Earth prior to this failure, and the decision to begin readout earlier than planned had proved very prudent indeed.


CHAPTER X

MISSIONS IV AND V: THE LUNAR SURFACE EXPLORED

The first three missions essentially satisfied the Apollo requirements for photographic data of potential landing sites. This opened the two remaining missions for other work. Photography could concentrate on specific areas of the Moon which scientists from various fields wished to explore more closely. It could also enable NASA cartographers to compile a much more accurate lunar atlas than any presently in existence.

Mission IV, as approved by the Ad Hoc Surveyor/Orbiter Utilization Committee on May 3, 1967, would attempt to accomplish some of these extended objectives. Specifically it would "perform a broad systematic photographic survey of lunar surface features in order to increase the scientific knowledge of their nature, origin, and processes, and to serve as a basis for selecting sites for more detailed scientific study by subsequent orbital and landing missions."¹

This mission, unlike the first three flights, required that Lunar Orbiter IV fly a nearly polar orbit. In such an orbit the spacecraft would acquire contiguous photographic coverage of a minimum of 80% of the frontside at 50 to 100 meters resolution. It would photograph as much of the Moon's farside as possible at the best possible resolution. The spacecraft could expose a total of 212 frames, and ground control planned to read out all photography in the priority mode immediately after processing. A final readout would be available if necessary.²

¹Lunar Orbiter Project Mission IV Description, prepared by the Lunar Orbiter Project Office, Langley Research Center, NASA, April 26, 1967, p. 3.

²Ibid., p. 4.
In preparation for the fourth mission the Lunar Orbiter Program and Project Offices conducted a flight readiness review on April 13, 1967, at the Eastern Test Range facilities. They found Lunar Orbiter IV (Spacecraft #7) and the backup (Spacecraft #3) ready for launch. Because the fourth Orbiter would fly a high polar orbit, it would be exposed to the Sun almost the entire time of the mission. This necessitated certain changes. A modified charge controller component was installed to reduce the rate of charge in the power system. Boeing engineers covered about 20% of the exterior of the equipment deck with mirrors to increase the heat rejection capability. A damaged micrometeoroid unit was removed and another unit installed. Finally the Inertial Reference Unit was removed for replacement of a failed capacitor. After reinstallation it successfully completed two attitude control system tests.\(^3\)

During the weeks before the fourth launch the Program Manager showed some concern over the failure of NASA's Applications Technology Satellite (ATS "A") to achieve its planned circular orbit around the Earth on April 6.\(^4\) NASA officials attributed this to the failure of the Agena rocket to re-ignite in orbit. Unofficially ATS program management described the cause for this as the failure of the Propellant Isolation Valve (PIV) in the Agena to close after the first burn. Scherer was hopeful that the PIV for the Lunar Orbiter Agena would test out successfully before April

\(^3\)Memorandum from SL/Manager, Lunar Orbiter Program to SE/Deputy Associate Administrator for Space Science and Applications (Engineering), April 14, 1967, pp. 2-3.

27, the planned date for the mating of the Agena with the Atlas booster.\(^5\)

Two areas involving previous mission and ground test problems also pertained to the successful performance of the fourth and fifth missions. The Traveling Wave Tube Amplifier (TWTA) onboard Lunar Orbiter II had experienced high helix currents. Ultimately it had failed to turn on during the final photographic readout phase, and some data were lost. The TWTA onboard Lunar Orbiter III had also experienced high helix currents and power output variations with temperature changes. Worse yet the TWTA in the ground test spacecraft for the Mission D Simulation Test failed to perform successfully under mission conditions. Scherer stressed that this test component was undergoing close examinations to determine the mode of failure. A delay of the fourth mission would hinge upon the seriousness of the test findings and the difficulty involved in resolving the problem.\(^6\)

Photo subsystem failure presented the other area of questionable spacecraft performance. Readout problems had marred the success of Lunar Orbiter III with unwanted repetition in readout and the inability of the film transport system to move film. Program investigators had not pinpointed the causes of these failures. However, the ten-day Mission D Simulation Test, just completed on April 12, partially compensated for these failures. During the test no problems involving the readout


\(^6\) Ibid., p. 2.
system had occurred, and this increased the likelihood of a successful fourth mission.

Last minute tests did not reveal any problems of a magnitude serious enough to delay a launch, and on May 4 Lunar Orbiter IV rode into space atop its Atlas-Agena D launch vehicle at 6:25 p.m., EDT. About thirty minutes after liftoff the Agena injected the spacecraft into a translunar trajectory. Early tracking data indicated that it was on course with the first midcourse maneuver scheduled for 1:00 p.m., EDT on May 5.\(^7\)

Early in Lunar Orbiter IV's journey to the Moon the Canopus star tracker experienced difficulty in acquiring Canopus. Glint from the Sun and earthshine probably caused this trouble. The star tracker had locked on to a celestial body, but program flight operators did not know whether it had acquired Canopus or the planet Jupiter which was in its field of view. Program operators planned to correct this situation by staging a roll reference maneuver during the first midcourse maneuver.\(^8\)

Passing through the Van Allen Belt Lunar Orbiter IV experienced a higher dose of radiation than had previous Orbiters: 5.5 rads recorded by the radiation dosimeter at the film supply cassette versus 0.75 rads on earlier Orbiters. However, the dosimeter located in the camera storage loopers registered 0.0 rads when it was turned on after the

\(^7\)Post Launch Mission Operation Report No. 1 from SL/Lunar Orbiter Program Manager to A/Administrator, May 5, 1967.

\(^8\)Ibid.
spacecraft had traversed the Van Allen Belt. During this time the spacecraft registered no micrometeoroid hits. 9

Shortly after noon EDT on May 5 Lunar Orbiter IV executed the planned midcourse maneuver. At 11:08 EDT on May 8 the spacecraft performed a burn of its rocket which deboosted it into an initial orbit around the Moon. The first orbital parameters were: apolune -- 6,111 kilometers; perilune -- 2,706 kilometers; inclination -- 85.5 degrees; period of orbit -- 721 minutes. 10

All systems performed well and within acceptable temperature limits. Lunar Orbiter ground control commanded the spacecraft to scan the Goldstone Test Film at 7:30 p.m. EDT on May 9. Deep Space Network stations at Goldstone, California, and Woomera, Australia, read out the film and received data of excellent quality. The TWTA onboard the spacecraft had been turned on for readout and would remain on for the duration of the mission. The spacecraft would execute thermal control maneuvers to suppress any overheating tendency of the TWTA. While the radiation dosimeter at the film storage cassette continued to read 5.5 rads, the dosimeter for the storage looper indicated a change from 0.0 rads to 0.5 rads. Ground control attributed this to background radiation from space which did not threaten the film. 11

9Ibid., p. 2.
In its sixth orbit around the Moon Lunar Orbiter IV began its first photographic pass at 11:46 a.m. EDT on May 11. As the spacecraft sped from south to north the photo system exposed five sets of four frames each at intervals ranging from 30 to 40 minutes. Passing over the vicinity of the lunar north pole, the spacecraft dropped out of sight and radio contact with ground control. Heading south it took one frame of the Moon's backside as it reached apolune (6,111.3 kilometers). By 8:40 p.m. EDT it had exposed a total of 27 frames, and ground control commanded the readout of this photography to begin. The first high and medium resolution pictures turned out excellently. 12

Although the spacecraft's radiation dosimeters had registered no change and it had only sustained one recorded micrometeoroid hit, Lunar Orbiter IV already had developed a serious problem which could jeopardize the whole mission. Telemetry data indicated that after the second set of four frames had been shot, the camera thermal door failed to close until ground control had sent additional commands to close it. After the third set of four frames had been exposed spacecraft telemetry did not confirm if the door had sufficiently opened. Ground controllers initiated a preliminary corrective action by commanding the door to open far enough in advance of the fourth set's exposure time to allow for additional commands if required.

NASA and Boeing engineers began immediately to analyze the problem. The danger of having the thermal door fail in the closed

position, thus ending all photography, forced flight operators to fly the spacecraft with the door open. This created the danger of light leakage which could fog portions of the film. Flight operators had to strike a delicate balance between keeping sunlight from leaking into the camera system and preventing the temperature within the system from dropping below the dew point of the gas which pressurized it. Too low a temperature could cause moisture condensation on the camera lens window and thus reduce the contrast of the photographs. Maintaining a balance between these two conditions led to extra maneuvers.

The danger of light leakage revealed itself early on May 13 during the readout of the exposures which the spacecraft had made since ground control had initiated contingency measures to cope with the camera thermal door problem. Portions of the photographs were light struck. NASA engineers deduced this by comparing readout results of film onboard the spacecraft which had been kept in the camera storage looper for one half hour with film which had been there five hours and longer. The quality of the exposures declined with the length of time the film had been on the looper before readout.

Lunar Orbiter Program personnel from NASA, Boeing, and Eastman Kodak attempted to solve the problem of the door. Flight operators devised and executed several tests to assess its reliability. These

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showed that the door could be partially closed, then reopened. Further tests placed the spacecraft in several orientations with the door partially closed. Ground control monitored the thermal response of the window and commanded the spacecraft to take photographs. On May 16 these photographs were read out, and they indicated that light leaks had ceased. Program officials concluded that their procedures were effective. However, the low contrast of some pictures indicated probable fogging of the lens window due to moisture condensation at low temperatures. Ground control maneuvered the spacecraft to raise the temperature of the lenses on orbit 14 and subsequent orbits.15

As of May 19 Scherer could report to NASA Administrator James E. Webb that his flight operations team had the photographic fogging problem under control. The team had established the following subjective grading system for pictures: 1) excellent quality, 2) light fogging, 3) heavy fogging, and 4) blank. The most recent high resolution photographs fell into the first or second categories, with most being graded excellent. A preliminary analysis of the photographic coverage during the first 60 degrees of longitude arc indicated that 64% of this area had been covered by grade 1 or 2 photography.16

Then early on Saturday morning, May 20, ground control picked up an anomaly during readout. The readout drive turned off in a normal manner without being commanded to do so. Ground control restarted it, but after scanning a short distance it stopped abruptly. Throughout

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the day this start-stop situation repeated itself, and the distance scanned varied from 0.2" to 12". NASA and Boeing engineers suspected that the readout encoder was falsely indicating a full readout looper. They began to analyze the problem while primary readout proceeded. Pictures obtained through readout proved that the new operational procedures for the camera thermal door continued to be effective, and no change in photography schedules was necessary.  

By 8:00 a.m. EDT on May 25 Lunar Orbiter IV was in its thirty-fourth orbit. It had photographed the lunar surface as far as the 100° west meridian, and ground control had recovered photographs up to about the 75° west meridian. The sector from 90° east to 45° east meridian, which the Orbiter had first photographed, it was photographing again in apolune because fogging had degraded the quality of the pictures. While photography proceeded well, flight operators and program managers believed that they had brought under control the premature termination of readout. They did this by using a repetitive series of commands to prevent the noisy encoder from stopping readout until commanded.  

Between May 21 and May 25, while problems with the thermal door and the readout encoder were being resolved, Lunar Orbiter IV experienced increased radiation dosage from major solar flares. Trutz Foelsche, primary designer and investigator of the radiation experiment, was able to make preliminary conclusions about the potential

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hazards to *Lunar Orbiter IV* based upon early data which the Space Flight Operations Facility had obtained from the spacecraft. On May 21 a solar event had produced low energy protons whose energies did not exceed 20 Mev. Since they had little energy these protons would hardly affect the camera film. Moreover, he concluded, the May 21 event was much less dangerous than the September 2, 1966, event which *Lunar Orbiter II* had encountered, and it had experienced no film fogging.

Readout problems worsened considerably on Saturday morning May 27. This meant a quick decision to cut the Bimat to escape the high probability that the Bimat would stick to the film, thus ending the photographic mission. At this time the spacecraft's photographic system had exposed and processed 163 frames of the 180 originally planned. Ground control successfully commanded *Lunar Orbiter IV* to cut the Bimat, but final readout presented more problems.

The erroneous encoder signals hindered film transport from the take-up spool considerably, and ground control had to improvise a non-standard procedure to get around this condition. Sending false picture-taking commands, mission controllers inched the film towards the take-up spool and then moved short segments of film back through the readout gate. By this procedure they successfully recovered 13 additional frames at the end of the film which might otherwise have remained stuck.

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on the take-up spool. Then ground control sent commands to the spacecraft to apply tension throughout the film system. The system responded normally to readout operations. Only 30 frames of the 163 which had been exposed remained to be recovered. 21

NASA ground stations completed the final readout on June 1. Lunar Orbiter IV photography had covered 99% of the Moon's front face at a resolution ten times or better than the best Earth-based telescopic photography. This coverage revealed significant, heretofore unknown, geological detail in the polar and limb regions of the Moon. Moreover, the spacecraft had obtained complete convergent stereo photographs of the Apollo zone of interest. Unofficially Lunar Orbiter IV photography increased to 80% the coverage of the backside of the Moon obtained during all four Orbiter missions. These accomplishments spoke highly for the organization and operation of the mission despite the problems which had been encountered. 22

The photographic mission terminated, Lunar Orbiter IV proceeded into its extended mission. Program officials planned to change the spacecraft's orbit so that it would approximate that planned for Lunar Orbiter V. The additional information which Lunar Orbiter IV would gather on the Moon's gravitational environment would be valuable in

21 Ibid.

22 Post Launch Mission Operation Report No. 13, June 5, 1967. The U. S. Air Force Aeronautical Chart and Information Center subsequently determined that of the total backside coverage of the Moon only 60% was usable for purposes of mapping the lunar farside. (Confirmed in a telephone conversation with Leon Kosofsky, Lunar Orbiter Program Engineer, September 15, 1967.)
planning the final Orbiter mission. In addition ground stations continued to track the second and third Orbiters. **Lunar Orbiter II**, launched in November 1966, was moving closer to the Moon's surface on an eventual collision course. Program officials planned to raise its orbit, thus extending its lifetime. **Lunar Orbiter III** would undergo a plane change in its orbit in addition to having it raised. This would provide new data on the lunar gravitational field for use in further mission planning and in the Apollo Program.

In March 1967, prior to the fourth mission, a working group within the Lunar Orbiter Program developed tentative objectives for the fifth and final mission. These called for a multi-site scientific mission with the capability of reexamining the eastern Apollo sites. A subgroup formed to determine specific sites for the last flight. ²³ On March 21 the entire working group met at the Langley Research Center to review the preliminary plans. The results of the review were sent to Boeing for further consideration before a presentation to the Ad Hoc Surveyor/Orbiter Utilization Committee at the end of the month.

The Lunar Orbiter Mission V Planning Group, which had come into being in March, met at the Jet Propulsion Laboratory on May 26 to review the Boeing Company's preliminary mission design for the fifth Orbiter. Of special interest was the problem of orbit design. The Group worked out an orbit design which would meet the needs of the multi-site mission

²³Ibid.

without violating spacecraft design restraints. The orbit would have an inclination of 85 degrees to the Moon's equator. Perilune altitude would allow two-meter resolution photography instead of one meter, in order to obtain more useful convergent stereo photographs at the higher altitude of 100 kilometers. At the higher perilune the cross-camera tilt would be reduced, offering better of the science sites.25

The Group decided to keep the Lunar Orbiter V apolune as low as possible and no higher than 1,500 kilometers above the Moon. Lighting conditions from the morning terminator would range from 8 degrees to 24 degrees. This offered the greatest potential relief of surface features, a requirement which would help scientists to analyse topo- graphic and geologic aspects of the Moon.26

By June 14 the Lunar Orbiter Program Office had completed the plan for the fifth mission, and the Ad Hoc Surveyor/Orbiter Utilization Committee approved it. As a result of Lunar Orbiter IV photography mission planners changed almost 50% of the sites they had initially selected for Mission V.27


26Ibid.

Lunar Orbiter V's mission objectives can be divided into photographic and non-photographic categories. The former comprised the primary part of the mission, the latter the secondary. The spacecraft would perform five basic photographic tasks. Task 1 entailed additional Apollo landing site photography, employing three modes of photography: near vertical, convergent telephoto stereo, and oblique. Task 2 would accomplish broad survey photography of unphotographed areas on the Moon's farside. Task 3 involved photography of additional Surveyor landing sites of high scientific interest to investigators. Task 4 would have the spacecraft concentrate on potential landing sites for the Apollo Applications Program with particular stress on their scientific interest. Finally Task 5 was related to the fourth in that it encompassed photography of a wide range of scientifically interesting sites.²⁸

The second category of mission objectives did not differ markedly from the first four missions. It included the following: (1) acquisition of precision trajectory information for use in improving the definition of the lunar gravitational field; (2) measurement of the micrometeoroid flux and radiation dose in lunar environment, primarily for analysis of the spacecraft's performance; and (3) providing the Manned Space Flight Network tracking stations with a spacecraft which they could track for purposes of evaluating the network and the Apollo

²⁸Ibid., pp. 4-7.
Orbit Determination Program. 29

Lunar Orbiter V would fly a nearly polar orbit inclined 85° to the Moon's equator. The spacecraft would deboost into an initial orbit with an apolune of 6,000 kilometers and a perilune of 200 kilometers. In this orbit it would perform photography of the lunar farside. The spacecraft would change to an intermediate orbit, reducing the perilune altitude to 100 kilometers and continue farside photo coverage. Finally the spacecraft would maneuver to a new orbit with an apolune of 1,500 kilometers and a perilune of 100 kilometers to execute the remainder of the photographic tasks. 30

As approved the mission plan called for a total of 212 film frames to be exposed. Of these it had allocated 44 frames to Apollo tasks and 168 frames to scientific areas, including those thought suitable for the Apollo Applications Program and for Surveyor landing sites. Five Apollo sites along the equatorial zone ranging from 42°56' east longitude to 36°11' west longitude and from 0°45' north latitude to 3°30' south latitude would be photographed. Potential Apollo Applications Program sites which Lunar Orbiter V would photograph included: the Littrow rilles, the Sulpicius Gallas rilles, the Imbrium flows, the craters Copernicus, Dionysus, Alphonsus, Dawes, Fra Mauro, the Copernicus secondary craters, the domes near Gruithuisen and Gruithuisen K, the Tobias Mayer dome, the Marius Hills, the Aristarchus plateau, the area of Copernicus

29Ibid., p. 3.

30Ibid., pp. 11-13.
CD, and the areas south of the crater Alexander on the northern edge of Mare Serenitatis. 31

What did mission planners use as criteria for selecting science sites? Donald E. Wilhelms of the United States Geological Survey, working with the Lunar Orbiter Program Office, describes one of the major criteria:

The primary criterion for selection of Mission V sites was freshness of the features in the site. Earlier Orbiter missions have shown emphatically that most lunar terrain has a subdued appearance at all Orbiter scales so that little new is learned from high resolution photography. Fresh young craters (mostly light) and fresh young rock units (mostly dark) that are not yet much modified by repeated cratering and wasting potentially reveal the most about rock type and origin, both in photographs and when sampled on the ground. Old terrains show effects of the processes that waste lunar slopes, and though these are of interest, they seem to be sufficiently sampled in high resolution photography by earlier Orbiter missions, except for very high and steep slopes. A few high and steep slopes and other non-fresh targets have been selected for the purpose of rounding out terrain sampling. 32

The fifth Orbiter mission would perform the most exacting, precision photography of all five missions. It also had the experience of the previous four flights to call upon in establishing greater confidence in mission controllers concerning operational procedures. As a

31 Ibid., pp. 18-21.

32 Ibid., p. 22. Wilhelms subsequently describes each site which Lunar Orbiter V would photograph, giving its geographic location and the main features of scientific interest. Lunar Orbiter photographs of each site accompany his descriptions. Mission IV photography proved extremely helpful in refining estimates of site freshness, in relocating Mission V sites, and in rejecting some previously selected sites.
result they could demand more of Lunar Orbiter V. By July 27 the spacecraft had successfully completed prelaunch tests, and NASA, Boeing, and Lockheed personnel had mated it with the Atlas-Agena on the launch pad. Program officials conducted the simulated launch exercise on July 28. The fifth mission was about to begin.

NASA launched Lunar Orbiter V successfully from the Eastern Test Range facilities on August 1, 1967, less than one year after the first Orbiter had made the long journey to the Moon. The author observed the final launch of the program on that day. Countdown had proceeded smoothly throughout the day with only one anomaly in the Agena, causing a short hold. Then it resumed until mid-afternoon. The launch was scheduled for 4:09 p.m. EDT, but this time would not be held.

Storm clouds swept over the Cape Kennedy area, bringing thunder-showers and lightning. The danger of lightning striking the fully fueled launch vehicle forced launch control to raise the gantry tower to its vertical position, thus offering protection against such an occurrence. Two-and-one-half hours ensued before ground control operators could resume the countdown. Rain drenched the whole area as a sudden squall line moved across the Cape. The threat of postponing the launch grew serious because the launch window on that day only lasted from 4:09 p.m. EDT to 8:00 p.m. EDT.

If the weather forced a postponement until the launch window on the following day, a partial loss of backside photography would result.

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Lunar Orbiter V was targeted for a high elliptical polar orbit to perform photography over the Moon's entire surface. The Moon rotates approximately 13° of arc on its axis per Earth-day. A delayed launch of one day would mean a loss of a 13° portion of the lunar backside to darkness. 34

The squall line hovering over the Cape moved slowly out to sea and the countdown resumed. Mission operators lowered the gantry tower once more. At T minus six minutes the spacecraft went on internal power. At T minus three minutes the spacecraft programmer clock began running. Outside the blockhouse at Pad 13 the Sun shone yellow in the west as the last minutes ticked away. T minus two minutes, ten seconds -- LOX tanking secured. In the east, out at sea the sky was dark and angry. Lightning continued to flash intermittently. T minus one minute and forty seconds -- Missile on internal power. A hot, permeating dampness hung in the air as more people gathered on the balcony of the second floor at the north end of the monitoring building to watch the launch. T minus sixty seconds -- Helium is internal. T minus forty seconds -- Prestart panel lights are correct. T minus nineteen seconds and counting -- Engine start. T minus four seconds -- Ignition. Zero -- Release. Liftoff. 35

34The author obtained this information in a discussion with Thomas Young from the Lunar Orbiter Project Office at Cape Kennedy on August 1, 1967.

At 18:33 hours EDT an orange-yellow cloud erupted from Pad 13. A few seconds later the great Atlas-Agena rocket ascended slowly, steadily with a sharp piercing roar which belatedly enveloped us in the awe-inspiring sight. The Atlas booster spouted long torch flames of white incandescence as it rose majestically against the darkened eastern sky. Thrusting, thrusting away from Earth, in forty-five seconds the space-bound vehicle disappeared through the high cloud cover on its ninety hour voyage to the Moon.

In the monitoring room program officials sat watching the large display panels as the various signals lit up, telling everyone that the different marks of the launch operation had been achieved. Early telemetry data indicated that all systems were functioning excellently. Fifty minutes into the mission the Deep Space Tracking Network station at Woomera, Australia, acquired radio contact with Lunar Orbiter V. It confirmed that the spacecraft had deployed its solar panels and its antennas, and its power system was operating on solar energy. All systems continued to perform normally and within acceptable temperature limits.  

Lunar Orbiter flight controllers at the Jet Propulsion Laboratory, where operations had shifted after the launch, executed the first mid-course maneuver at 2 a.m. EDT on August 3. The maneuver corrected the spacecraft's trajectory, which was about 7,000 kilometers off of the aim point, for deboosting into lunar orbit. The spacecraft

36 Post Launch Mission Operation Report No. 1 from SL/Lunar Orbiter Program Manager to A/Administrator, (Status as of 8:00 a.m. EDT, August 2, 1967).
carried out a roll of plus 42.1°, a pitch of plus 29.1°, and a burn of its rocket for 26 seconds. These maneuvers increased its speed an additional 29.76 meters per second which would put **Lunar Orbiter V** on course for the planned arrival time at the Moon. No second midcourse maneuver was necessary.  

During the cislunar transit the spacecraft had no difficulty acquiring Canopus before the midcourse maneuver. The radiation dosimeter at the film supply cassette registered a dose of 0.75 rads as the spacecraft passed through the Van Allen Belt. After passage the dosimeter in the camera storage loopers was turned on, and it registered zero rads. The ship recorded no micrometeoroid hits, and all systems continued to perform well.  

At 12:48 p.m. EDT on August 5, after executing a roll and a pitch maneuver, the spacecraft fired its 100-pound-thrust rocket for 8 minutes 28 seconds and decelerated by 643 meters per second into the gravitational captivity of the Moon. The initial orbital parameters obtained were: apolune -- 6,023 kilometers, perilune -- 194.5 kilometers, inclination 85.01°, period -- 8 hours, 30 minutes. One-and-a-half hours after orbit insertion, ground control commanded **Lunar Orbiter V** to scan the Goldstone Test Film. Readout showed high quality data. Subsequently flight controllers prepared for the major photographic work of the mission.  

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38 Ibid.  
The photographic mission commenced at 7:22 p.m. EDT on August 6. At this time the spacecraft took its first photograph of the Moon at a distance of about 6,000 kilometers from the lunar surface. The target was a previously unknown area on the farside. Following this it executed a maneuver early on August 7 which lowered the perilune to 100 kilometers while maintaining a 6,023 kilometer apolune. The spacecraft continued farside photography and exposed 18 out of 19 frames during this first part of the mission. The nineteenth was a "film set" frame, moved through the photo system in an eight hour interval to prohibit film and Bimat from setting. While this was a planned item in the film's budget the decision which program officials made in the early hours of August 7 changed one frame significantly. They allocated another "film set" frame to take a photograph of the Earth instead of passing unexposed through the system.  

Site VA-9, as the Earth photograph was identified, had not been in the original plan. Program officials decided, however, that the position of Lunar Orbiter V relative to the Moon and the Earth and the Earth's position relative to the Sun afforded a very fine opportunity to take such a picture. The necessity to move film in the photo system at certain intervals, regardless of photographic targets, meant that the system processed a certain portion of the film unexposed. Programmers, therefore, implemented a plan to make an Earth photograph when the spacecraft neared apolune between orbits 7 and 8. Since the

\(^{40}\)Ibid., p. 2.
spacecraft's orbit geometry kept it in view of the Earth at all times, it was possible for it to exclude any part of the Moon's surface from the photograph.\textsuperscript{41}

Exactly seven hours, twenty-three minutes elapsed between the exposure of the previous photograph of Site VA-8 and the moment when \textit{Lunar Orbiter} \textit{V} made the historic photograph of the nearly full Earth on August 8 at about 9:05 Greenwich Mean Time. Shutter speed was 0.01 second, but the Earth's high albedo caused some overexposure of the film. This was unavoidable. Later the Langley Research Center successfully applied the image enhancement technique, using the magnetic-tape video record of the readout, to bring out details which would not have shown up in a negative reconstructed from raw readout data. Approximately 149° of arc of the Earth's surface appear clearly in the photograph, (see photograph in Appendix). It graphically illustrates the possible synoptic weather observations which a satellite could conduct in cis-
lunar space or which could be made from the Moon.\textsuperscript{42}

Very early on August 9, EDT, \textit{Lunar Orbiter} \textit{V} executed a second orbital maneuver which reduced its apolune from 6,023 kilometers to 1,500. The final orbital parameters were: apolune -- 1,499.37 kilometers, perilune -- 98.93 kilometers, inclination -- 84.76°, period -- 3 hours, 11 minutes. All spacecraft systems continued to perform normally. The micrometeoroid detection experiment had recorded one hit, and the radiation level registered by the dosimeter at the film cassette remained

\textsuperscript{41} \textit{Lunar Orbiter} \textit{V} Photography, NASA CR-1094, prepared by The Boeing Company, June 1968, p. 140.

\textsuperscript{42} \textit{bid.}, pp. 140-141. Picture and computer schematic on pp. 142-143,
constant at 1.00 rads, up from 0.75 rads. In the following days the spacecraft continued to perform its mission as planned without experiencing any troubles. By August 14 it had completed 51 orbits and had exposed 107 of 212 film frames. Sixty frames had been read out, of which the picture of Earth showed remarkable detail from such a great distance.

The photographic mission ended on August 18 when the spacecraft made its last photograph and cut the Bimat at 11:20 p.m. EDT. In all it had successfully covered 5 Apollo sites, 36 science sites, 23 previously unphotographed areas on the lunar farside, and a nearly full view of Earth. The Apollo site coverage included 5 four-frame sets of convergent stereo photographs and 4 westward-looking oblique views. Lunar Orbiter V had transmitted seventy-eight percent of the high resolution and seventy-five percent of the medium resolution photography to Earth at a rate of about 4 frames per orbit or 27 frames per day as of August 21, and ground control expected to conclude readout by August 26.

On September 2 Homer E. Newell, Associate Administrator for Space Science and Applications, certified that the fifth mission was an unqualified success based upon prelaunch objectives. Deputy Administrator Robert C. Seamans, Jr., concurred on September 6. Both

\[^{43}\text{Post Launch Mission Operation Report No. 5, August 9, 1967.}\]
\[^{44}\text{Post Launch Mission Operation Report No. 8, August 14, 1967.}\]
\[^{45}\text{Post Launch Mission Operation Report No. 10, August 21, 1967.}\]
NASA officials also assessed the whole program as successful, based upon five missions flown out of five planned. Indeed the final Orbiter had capped an impressive effort by the Office of Space Science and Applications to bring man closer to stepping down upon the lunar soil and understanding what it was that he would be walking on in the near future.

The status of the fifth spacecraft remained good following termination of readout early on the morning of August 27. Lunar Orbiters II and III also continued to orbit the Moon and provide extensive data on the lunar environment and its gravitational field. These three spacecraft served the Manned Space Flight Network as tracking targets for training the personnel who would track Apollo.

Lunar Orbiter II had sufficient attitude control gas to survive until early November. Ground control operators planned to impact it into the Apollo zone on the Moon's surface even though analysis of tracking data indicated that it could probably remain in orbit one to two years longer. Once the spacecraft lost its attitude control gas, however, it would be a derelict in orbit, beyond the control of ground operations. Program officials deemed it necessary, therefore, to crash the spacecraft while they were able so as to avoid any potential hazard to a future manned mission. They also planned to lower Lunar


Orbiter III's apolune to make its orbit as circular as possible for further Apollo network training. However, expiration of its gas would must soon mean that it, too, be crashed. The fifth Orbiter had just begun its extended mission late in August. Its orbit would be changed on October 10 so it might better survive the umbral eclipse of October 18. (Program engineer Leon Kosofsky and mission operators changed the orbit so that the spacecraft would pass through the eclipse and solar occultation by the Moon at the same time.) Apollo network trackers would continue to track the spacecraft as long as possible to increase their experience in preparation for manned lunar missions.48

On September 11 the Lunar Orbiter Program Office issued a statement of the plans for terminating the life of the three remaining Orbiters. It stated briefly:

The policy is to track the Orbiter spacecraft until the approach of loss of attitude control as indicated by the nitrogen pressure. While the spacecraft is still controllable, the engine will be fired so as to cause impact with the lunar surface. The impact will be made within the Apollo zone if feasible. At this time, it appears that Orbiter II will be impacted in early November, Orbiter III in mid October, and Orbiter V in mid summer 1968. Contact with Orbiter IV has been lost.49

Following the final acquisition of all Lunar Orbiter V photographic data, Lee R. Scherer issued a summary statement about the program's

48 Ibid.
achievements. Among these he stressed that Lunar Orbiter II photography had led to the identification of the Ranger VIII impact point on the Moon. Orbiter III photography had located Surveyor I and Surveyor III on the lunar surface. The fifth Orbiter had photographed major lunar features of scientific interest at a resolution 100 times better than Earth-based telescopes could achieve under ideal observation conditions. All Orbiters combined had photographed the entire lunar surface at a better resolution than Earth-based telescopes could attain and had surveyed for the first time the heavily cratered farside of the Moon. The spacecraft had provided valuable data contributing to the determination of the Moon's gravitational field. Finally one of the program's most significant accomplishments had been to advance the Apollo Program in a way other than photographic site certification. Five Orbiters had enabled the Manned Space Flight Program Network to train personnel in tracking and to check out equipment and computer programs for the upcoming manned lunar missions. This suggests strongly that not the Office of Manned Space Flight would/have obtained such experience had NASA not flown the Lunar Orbiter spacecraft.50

The chronology of the Lunar Orbiters concluded in the following way. On October 9 ground controllers commanded Lunar Orbiter III to impact on the Moon. They did likewise for Lunar Orbiter II on October

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50 Memorandum from SL/Assistant Director for Lunar Flight Programs (Lee R. Scherer) to SL/D. Pinkler, Subject: Lunar Orbiter Program Highlights, September 13, 1967, pp. 1-2.
11. They had lost communications with Lunar Orbiter IV on July 17, 1967, and presumed that its orbit had decayed sufficiently to allow it to crash into the Moon late in October. Yet they had no evidence confirming this. Lunar Orbiter V continued to fly its extended mission until unexpectedly it experienced an anomaly between January 26 and 28, 1968, which threatened its orbit safety. A sudden loss of pressure in the nitrogen tanks forced ground controllers to impact the spacecraft prematurely on the Moon to avoid losing it in orbit. They conducted this final maneuver on January 31.\textsuperscript{51} This brought the operational phase of the Lunar Orbiter Program to a close.

CONCLUSIONS: LUNAR ORBITER'S CONTRIBUTION TO SPACE EXPLORATION

The Apollo Program utilized Lunar Orbiter data more than any single NASA office or outside agency in the months following each Lunar Orbiter mission and in the period between the last mission and the time Neil Armstrong and Edwin Aldrin first set foot upon the Moon's Sea of Tranquility on July 20, 1969. The story behind Apollo site selection activities is beyond the scope of this history. Nevertheless, a brief summary of Lunar Orbiter's relationship to Apollo mission planning will enable the reader to distinguish the role which Lunar Orbiter played in the Apollo Program as a result of cooperation between the Office of Space Science and Applications and the Office of Manned Space Flight.

Even before Lunar Orbiter V flew, the Office of Space Science and Applications entertained the prospect of a sixth Orbiter mission. Boeing had nearly enough parts to assemble another spacecraft at an initial cost of about $13 million. A gamma ray experiment also existed which scientists desired to fly on a sixth Orbiter. Its inclusion would raise the cost of the mission by about $3 million. However, the necessity to relocate personnel on the Lunar Orbiter team to other jobs presented a major problem blocking a sixth mission.  

Lunar Orbiter Program officials estimated that if the mission of Lunar Orbiter V failed, the program would have to fly a sixth Orbiter. However, refurbishment of a sixth spacecraft required several parts:

1Comments on Second Draft Memo (Undated), June 26, 1967. See also memorandum from SL/Manager, Lunar Orbiter Program to SL/Acting Director, Lunar and Planetary Programs, Subject: Lunar Orbiter 6, April 6, 1967.
new solar panels for example. The Lunar Orbiter Program Office examined the needs and the lead times required for a sixth mission during May and June 1967. By the beginning of July program management knew that OSSA soon had to make a commitment to another mission if it wanted to avoid shifts of personnel /at Langley and Boeing following the photographic phase of Mission V. Known too was the simple fact that the longer NASA officials waited to approve go-ahead for a new mission, the greater the costs and the more severely the management arrangements would impact on other NASA programs.²

On July 5 Scherer issued a statement summarizing the objectives of the fifth mission and the rationale behind a sixth Orbiter flight. He pointed out that the total cost of each of the first five missions had amounted to $40 million apiece. The sixth mission would cost less than one third of this. Even if the fifth mission successfully achieved all planned objectives, a sixth mission could accomplish very valuable and different goals. Briefly it could (1) perform a total survey of the farside of the Moon at 60 to 80 meters resolution, (2) take a concentrated look at the best Apollo Applications Program sites as determined through analysis of photographic data from Lunar Orbiter E, and (3) closely survey additional areas of high scientific interest. If Mission E failed, a Mission F would be necessary, according to Scherer.³

The Lunar Orbiter Project Office sent a memorandum to Scherer's

²Ibid., p. 2.

office on July 12 detailing the options open to OSSA for a sixth mission. The first option involved a go-ahead decision by mid-July. The details were these: (1) that refurbishment and processing the spacecraft required four months and was the pacing item; (2) cost of launching Lunar Orbiter F late in November would amount to $12.75 million; (3) a launch by that time would retain launch success capability of the previous launches; (4) this option provided the greatest retention of overall experience in the Lunar Orbiter team. The second option was the same as the first except that it allowed for cancellation of preparations for a sixth flight early in September. At that time data from Lunar Orbiter V would be available. If the mission were successful and the need for another mission were insufficiently justified, then the Lunar Orbiter Program could cancel the additional mission at a cost of about $4 million.

The third option was the least manageable. It required that NASA postpone the July go-ahead but authorize funds to hold the team and the hardware in readiness until evaluation of the Lunar Orbiter V mission results. This option would extend the earliest possible launch date from late November to late January 1968 and raise the cost of a sixth mission to $16.5 million. It would also impact on the launch of OCO-E and would delay the Air Force takeover of the launch complex 13 facilities. In view of these circumstances the Langley Lunar Orbiter Project Office recommended that only.

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5 Ibid., p. 2.
the first option be considered and that NASA Headquarters approve go-ahead prior to July 22, 1967.6

On July 14, 1967, Homer E. Newell sent NASA Deputy Administrator Robert C. Seamans, Jr., a summary of the alternatives involved in a sixth mission. He reiterated the three options which the Langley memorandum had specified and underlined Langley's position in support of a July go-ahead for a late November launch. He stressed to Seamans that a delayed decision would have major effects on management problems, costs, and schedules in the Office of Space Science and Applications.7

Seamans weighed the need for the sixth mission and decided that NASA funds would better support other activities. On July 24, 1967, Scherer officially informed Langley that NASA Headquarters had decided against a sixth Lunar Orbiter mission. However, he stated in his telegram to Floyd L. Thompson that a remote possibility for a reversal existed if the fifth mission failed. He requested Langley to proceed to phase out the program but to retain mission-peculiar test, launch, and flight operations equipment until it had completed the photo readout of Mission V. This retention did not apply to personnel, and Langley was to commence reassignment.8

Because Lunar Orbiter V succeeded beyond expectations in carrying

6Ibid.

7Memorandum from S/Associate Administrator for Space Science and Applications to AD/Deputy Administrator, Subject: Considerations related to decision on a sixth Lunar Orbiter, July 14, 1967.

8Telegram, priority, unclassified from Lee R. Scherer, Manager Lunar Orbiter Program to Langley Research Center, Attention: Dr. F. L. Thompson, Mr. E. C. Draley, Mr. C. H. Nelson, July 24, 1967.
out its mission objectives, its success proved that cancellation of the
sixth mission had been a prudent move. Moreover, the Apollo Program
had virtually no need for the kind of data a sixth mission might have
obtained; it would not have been decisive in mission planning.
Indeed, at the Apollo Site Selection Board meeting on March 30, 1967,
Apollo Program officials had agreed that, "although further data from
Lunar Orbiters D and E will be requested, the photography already re-
ceived from Orbiters I, II, and III meets the minimal requirements of
the Apollo Program for site survey for the first lunar landing." They
had arrived at this conclusion by detailed screenings of Lunar Orbiter
data using the following steps:

1. Construct Lunar Module landing ellipses and radar approach
templates from photo support data.

2. Outline reject areas on medium resolution photographs.

3. Scan remaining area where high resolution coverage is
also available.

4. Select better ellipse locations with favorable radar ap-
proaches. Identify obstacles.

5. Select best ellipse based on landing and radar obstacles,
count craters, and compute 'N' number from medium resolu-
tion photos. For most favorable sites continue evaluation
with high resolution photography.

6. Evaluate ellipses on high resolution photography and com-
pute 'N' number.

The Apollo Site Selection Board (ASSB) had begun its work at its

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9Memorandum from MA/Apollo Program Director, Subject: Minutes of
the Apollo Site Selection Board Meeting, March 30, 1967, p. 5.

10Ibid., Attachment -- Steps in Lunar Orbiter Screening.
first meeting on March 16, 1966. No Lunar Orbiter or Surveyor spacecraft had yet flown, and, therefore, all discussion of site selection requirements depended upon Ranger and Earth-based telescopic photography. Lunar Orbiter would soon change Apollo Program thinking about landing sites. At the first ASSB meeting the members identified a number of potential sites on the basis that finally chosen sites would most likely be among them.11

By the following ASSB meeting Surveyor I had successfully landed on the Moon in Oceanus Procellarum, north of the crater Flamsteed. The first Lunar Orbiter mission, scheduled for early August, would attempt to photograph the Surveyor. Lunar Orbiter Program officials would adjust the positions of sites A-9 and A-10 to combine two blocks of photography for greater surface coverage of the area in which the unmanned spacecraft had touched down. In addition to this change in Mission I of Lunar Orbiter, Norman Crabill and Thomas Young of the Lunar Orbiter Project Office presented the ASSB meeting on June 1 recommendations for Lunar Orbiter Mission B. They believed that each Mission B site contained areas smooth enough to qualify as candidate Apollo sites. Finally the Apollo Program representatives, after reviewing the target sites for Lunar Orbiter Missions A and B, concluded that these sites would satisfy all known Apollo requirements based upon the assumption that the surface of the Moon proved hospitable at each one.12

11 Memorandum from MA/Apollo Program Director, Subject: Minutes of Apollo Site Selection Board Meeting, March 16, 1966, document dated May 5, 1966.

At the June 1 meeting Oran Nicks of OSSA asked Apollo Program people if they had any requirements for lunar landmarks which Orbiter could photograph. Owen E. Maynard of the Manned Space Flight Center, who had presented the Apollo Site Selection Plan to the meeting, replied that the program had no plan at the time to use landmarks for updating orbits of the Apollo spacecraft. However, it would be desirable if such landmark sites could be located within a block of Orbiter photography containing a proposed Apollo landing site.\textsuperscript{13}

By the December 15 ASSB meeting \textit{Lunar Orbiter I} had obtained medium resolution stereo photography of nine potential Apollo landing sites. \textit{Lunar Orbiter II} had photographed thirteen potential sites in medium resolution stereo and high resolution monoscope. Lawrence Rowan of the United States Geological Survey interpreted to those present the data of the lunar surface with respect to impact craters, volcanic fields, and mass wasting of the top layer of the Moon's soil. He made the following points:

1. Older mare areas such as those in \textit{Lunar Orbiter II} photographs of Site II P-6 do not have the problem of crusts and lava tubes as most likely is the case in young areas such as Site II P-2.

2. \textit{Surveyor I} photographs in Oceanus Procellarum exhibit more surface rocks than are found in Sinus Medii and Mare Tranquillitatis, suggesting that it might be younger and have a thin surface layer.

3. Slopes in older highland and smoothed mare craters, which show "patterned ground," may be unstable due to collapse

\textsuperscript{13}\textit{Ibid.}, p. 3.
or landslide dangers. 14

Analysts for the Lunar Orbiter and Apollo Programs had chosen nine sites from Lunar Orbiter I photography and had applied Apollo site selection criteria in an effort to locate Lunar Module landing areas. The December 15 ASSB meeting reviewed the results. Twenty-three areas proved large enough to contain a landing ellipse. These were undergoing further study, and Apollo Program personnel evaluating them would make detailed crater counts of each during the next stage of selection. Following the preliminary analysis eight of the twenty-three areas merited special study. 15 The process of screening the Lunar Orbiter data is given in the diagram on the next page.

Further analyses of Orbiter photography brought more confirmation that the Lunar Module design was correct and offered sufficient capability to land on the Moon, based upon landing site data determined from Orbiter photographs. At the March 30, 1967, meeting of the ASSB Donald C. Cheatham from MSC pointed out that "the LM redesignation capability permits a change of touchdown point of 10,000 feet crosstrack at high gate (90 feet per second delta V, command at 30,000 feet down range). Visibility restrictions do not permit up-range redesignation. Preliminary

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14 Minutes of Apollo Site Selection Board, December 15, 1966, document dated March 7, 1967. Site II P-6 is located in the southwestern area of Mare Tranquillitatis (approximately 23 degrees east longitude, 2 degrees north latitude). Site II P-2 is located east of the crater Maskelyne and northeast of the crater Censorinus (approximately 33 degrees east longitude, 3 degrees north latitude).

PRELIMINARY SCREENING

**INPUTS:**
SUPPORTING DATA PHOTOGRAPHS

- CONSTRUCT LM LANDING ELLIPSES AND RADAR APPROACH TEMPLET TO PHOTO SCALE
- OUTLINE OBVIOUS REJECT AREAS
- DETERMINE CRITICAL CRATER DIAMETER

1. OUTLINE SMOOTH AREAS LARGE ENOUGH FOR LM ELLIPSE WITH SMALL SLOPES AND GOOD RADAR APPROACH
2. TRANSFER TO HIGH RESOLUTION PHOTO

EVALUATE & DOCUMENT
1. OUTLINE AND MEASURE REJECT AREAS IN LM ELLIPSES
2. EVALUATE & NUMERICAL RATE ELLIPSES
3. COLLATE WITH GEOLOGIC SCREENING
4. COLLATE WITH EXISTING PHOTO
5. ASSIGN PRIORITIES

1. STEERING COMMITTEE
2. MSC GROUPS PERFORMING DETAIL ANALYSIS
3. DOD GROUPS FOR MAP PRODUCTS
4. USGS FOR GEOLOGIC PRODUCTS
5. ASSB

(Source: Minutes of the Apollo Site Selection Board Meeting, December 15, 1966, ATTACHMENT G, p. 3.)
examination of the Lunar Orbiter photography indicate that this capability will be sufficient for crater avoidance." 16 Already Lunar Orbiter had told Apollo mission planners very much about the areas where they could and could not send the Lunar Module.

Finally the December 15, 1967, meeting of the ASSB at Houston had the photographic data of all five Lunar Orbiters upon which to base its judgments. The major criteria for selection of the landing sites subsequently depended upon performance constraints of the Apollo spacecraft, particularly the Lunar Module. 17 Lunar Orbiter had provided the photographic data which the Apollo Program had originally requested. Surveyor data continued to come in from three landed spacecraft in the Apollo zone of interest. Two more Surveyors would land in different areas of the Moon before that program concluded operations. Beyond this Lunar Orbiter photography did not constitute a major criterion for the final selection of Apollo landing sites. This had to depend upon performance constraints of the Lunar Module. At this point Lunar Orbiter had fulfilled its primary supporting role in the manned lunar landing mission -- Apollo.

There is doubtless much more that can be said about the Lunar Orbiter Program and its relationship to Apollo. However, this must be the task of future historians. It now remains for this author to draw his conclusions about the Lunar Orbiter Program. These are preliminary and any error must be attributed to the author.

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The Lunar Orbiter Program, like the Apollo Program, has unfolded in a politically charged atmosphere. The national commitment to land Americans on the Moon within the decade of the sixties imposed certain directions and a sense of urgency on the course which the National Aeronautics and Space Administration has taken in both programs. It also placed certain limitations on unmanned exploration of the Moon. First, the Apollo Program provided the raison d'être for Lunar Orbiter. This meant that the Office of Space Science and Applications undertook an engineering feat in 1963 whose most immediate applications would directly support the objectives of the Apollo Program: to design and build a system and a mission capable of taking men to the Moon and returning them safely to Earth. Lunar Orbiter contributed significantly to Apollo mission design, the hardware having been designed and built before Lunar Orbiter mission operations began.

The American commitment for a manned lunar landing and the needs of Apollo have eclipsed unmanned scientific exploration of the Moon during the sixties. The Office of Space Science and Applications thus also stands in the shadow of the Office of Manned Space Flight in lunar exploration. Nevertheless, the highly successful Lunar Orbiter Program has proved the role which unmanned, long-life orbiters can play in future space exploration. It is no coincidence that the Langley Research Center which sired Lunar Orbiter now has the responsibility for the Mars-orbiter of the early seventies: Viking.

American exploration of the Moon, involving the pure sciences, has obtained the space-proven systems to conduct specific observations and
to gather precise data on the lunar environment, either with or without men. Yet in the immediate future it appears highly unlikely that unmanned exploration of the Moon will take place unless it has a direct relationship to future manned lunar landings. This, in turn, characterizes the National Aeronautics and Space Administration as it leads America into the second decade in space.

The once ambitious unmanned lunar exploration program, Surveyor Orbiter, which would have carried a wide variety of scientific instruments and experiments to the Moon's environment, much as the Soviet Luna and Zond spacecraft have, has not been attempted again. Perhaps it was too ambitious; and the road taken to land men on the Moon proved politically more reassuring in any case. Certainly the five out of five successful missions of Lunar Orbiter and the desire to fly a sixth mission substantiate the philosophy within NASA that unmanned lunar probes serve best when their objectives are simple, limited, and mutually supportive of each other and of manned exploration. In this respect Lunar Orbiter aided Apollo and Surveyor by performing yeoman labor which allowed safe lunar landings to take place.

Had NASA directed the five missions of Lunar Orbiter to conduct scientific investigations of the Moon, independently of Apollo, then most likely the missions would have been different. Mission IV might have been the first to fly. With a total survey of the Moon, scientists could then have selected the most interesting sites for closer, more detailed investigations. Surveyor spacecraft might have landed elsewhere than they did; and Apollo might have flown significantly different missions.
This has not happened. If Lunar Orbiter had been totally independent of manned exploration, much like the Mars Mariner spacecraft have been, then, perhaps, only some of the missions would have flown photographic payloads. Numerous experiments to analyse the Moon's environment existed or could have been designed to fly on an Orbiter as was the case with Explorer XXXV. Yet in no case could Lunar Orbiter have brought back to Earth samples of the Moon's surface. Nor could it have satisfied the political commitments which the United States had made as a result of the early Soviet thrust into space. In fact Lunar Orbiter was inseparably bound to the goals of the American manned lunar exploration effort.

The bond between Lunar Orbiter and Apollo fostered cooperation between the Office of Space Science and Applications and the Office of Manned Space Flight which otherwise might have developed more slowly and less affirmatively. This brought about a higher level of integrated activities between various NASA centers far sooner than might have occurred under different circumstances. The problems encountered in the Ranger and Surveyor Programs early in the sixties forced NASA Headquarters to search for other means of accomplishing the tasks of space exploration, and this led it to delegate to the Langley Research Center a new area of responsibilities beyond its traditional role in research and development. In turn this move has broadened the agency's base for accomplishing ever more complex and sophisticated objectives in the American space venture.

It would be unjust, however, to claim that without Lunar Orbiter photography, Apollo could never have flown so early or America could never have landed men on the Moon in 1969. Orbiter greatly illuminated
Apollo's way, but it is highly conceivable that the Apollo Program could have flown one or more manned orbital photographic missions before planning a landing. No Orbiter data went into the design of the Apollo spacecraft system and the Lunar Module, and, indeed, the missions of Apollo VIII and X demonstrated the orbital capabilities of the spacecraft. The main objectives of these two missions were the testing of the systems and the mission design short of an actual landing on the Moon. The photography conducted by the astronauts proved limited but highly valuable to lunar exploration. Yet in contrast the Lunar Orbiter photography covered almost the entire Moon and captured scenes of the lunar landscape under predetermined lighting conditions and at altitudes which allowed Lunar Orbiter Program officials to obtain exact information about the landing sites which the Apollo Program had requested, at a time when such data proved most valuable in Apollo mission design.

Thus Lunar Orbiter saved Apollo time. It also gave Apollo flight operations personnel experience in tracking five spacecraft in lunar orbit. It provided very valuable data on the Moon's gravitational field and its effects upon orbiting spacecraft. It aided the Surveyor Program in selecting landing sites. Then it photographed landed Surveyors. Lunar Orbiter V photography of the crater Tycho and its vicinity proved instrumental in the decision to land Surveyor VII north of Tycho in an area of high scientific interest but whose topography greatly reduced the chances of a soft landing. Surveyor VII landed successfully and provided invaluable data of an area of the Moon where astronauts in a Lunar
Module could not land under present systems and orbital constraints.\(^{18}\) The combined work of Lunar Orbiter V and Surveyor VII has given NASA scientists a close look at an otherwise remote and forbidding, but very interesting part of the Moon. Such can be the value of unmanned exploration.

The successful achievements of Lunar Orbiter and Surveyor also have far-reaching implications for planetary exploration. Deputy Associate Administrator for Space Science and Applications Oran W. Nicks outlined some of them in an address to the American Institute of Aeronautics and Astronautics on December 5, 1968. He stated that experience gained in the initial stages of unmanned lunar exploration will have direct applications in the exploration of the red planet Mars in the seventies.\(^{19}\)

Exploration of Mars at close range commenced in 1965 with the fly-by of Mariner IV. It provided man with his first detailed glimpse of the Martian surface; surprisingly its pictures revealed many craters, showing that Mars has similarities to the Moon. Early in August 1969 Mariner VI and Mariner VII brought even closer views of the red planet when they flew by, taking pictures and sampling the Martian atmosphere and surface temperatures. These three space probes have opened up many more areas of questioning than they have answered, and, as a result, the early seventies will witness intensified unmanned exploration of Mars. In 1971 NASA will apply the Lunar Orbiter concept to Mars when it sends


\(^{19}\) Ibid., pp. 10-11.
two Mariner-class orbiters on long-life survey missions of the red planet. In 1973 two more orbiter missions and two lander missions will augment this work. Although the weight and the payloads of these Mars probes will be substantially lighter than Lunar Orbiter, the spacecraft will profit from the Orbiter experience, and the Viking Program at Langley will not have to build from scratch.

This relationship demonstrates that the Office of Space Science and Applications has successfully built upon the cumulative experience and knowledge of its programs during the course of the past decade. Among other achievements, this work has proven the Orbiter concept and the feasibility of landing an unmanned spacecraft on another celestial body. Viking can draw upon an increasing treasury of successfully proven concepts in its efforts to further the unmanned exploration of the solar system. In so doing it will also add to that treasury. Perhaps Oran Nicks best summed up the meaning of this work when he said:

Burning questions of immediate concern to you and me will be addressed by use of our new tools: 'Is there life elsewhere? Has life existed on nearby planets and disappeared for any reason? Can nearby planets be made suitable for life?'

Together, orbiters and landers form a powerful team for the study of Mars and for seeking answers to these questions. Together, they will continue to extend our capabilities in what is probably the most challenging, open-ended arena for expansion of science and technology in the decade ahead.

Men have landed on the Moon and have scratched its surface. It still remains a mysterious body, and exploration of it has barely commenced. Mars, Venus, Jupiter, and the other planets beckon men to pursue

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20 Ibid., p. 12.
the quest for an answer to the origins of Earth, the solar system, and, eventually, the universe. This quest will alter man's thinking about himself and his existence in the universe as radically as Copernicus, Kepler, and Galileo changed and destroyed the ancient Aristotelian-Ptolemaic concepts of the universe which had shaped medieval man's thinking about his existence. Five hundred years ago men believed the Earth was the center of the universe. But today the first leap to the Moon has shown mankind just how small and finite the Earth is, a blue-white gem in the blackness of space. Lunar Orbiter assisted in making that initial jump. To this extent it has also made for itself a place in the history of space exploration.
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The investigators conducted laboratory experiments using soils with grain sizes ranging from 0 to 125 microns and gravels ranging from 2 to 4 millimeters with gradations and layering. Tests were run under air and vacuum conditions to determine behavior of water at various flow rates and temperature levels on test soils. Results showed that in the presence of air water formed terrestrial-like stream channels. In a vacuum at freezing temperatures water formed dendritic ice masses and continued to flow under the ice, frequently penetrating to the surface and freezing. Water then sublimated, leaving a hummocky surface. Some soil downslope movement occurred, but no stream channels developed. Results show that ice will readily form in a vacuum to a thickness which allows liquid water to exist under it. Model streams produced in a vacuum did not erode rille-like channels. Results support Lingenfelter's predictions (Science, Vol. 161, p. 266).


There is a major implication in the mathematical calculations of the Moon's orbit as rechecked and improved by H. Gerstenkron. About one billion years ago the Moon, a separate planet orbiting the Sun, passed very close to Earth. Both bodies continued to attract each other until the Moon assumed a retrograde orbit about the rapidly spinning Earth. The Moon moved within the Roche limit in a polar orbit around
Earth, causing part of the lunar surface to break away and bombard Earth. Following this the Moon began to recede from Earth until it came to occupy its present orbit. Loosened materials fell back on the Moon as meteors, making major craters. Geological investigations might substantiate Gerstenkorn's theory.


Infrared observations of the Moon in the 8- to 14-micron atmospheric window have delineated macroscopic lunar surface thermal behavior. Shorthill has discovered further lunar thermal anomalies. The craters Aristarchus, Copernicus, and Tycho cool much less rapidly than surrounding areas during eclipse. The observations made by the authors have not determined the geometric scale of the structure of hot and cold regions. Surface rocks in these areas may be responsible for the less rapid cooling rates because they are probably thermally connected to a subsurface temperature of 200 degrees Kelvin.


This report describes the use of Lunar Orbiter II photographs in conducting a test in which the subjects were required to fix the location of a Lunar Module in a simulated crater field near U. S. route 89, northeast of Flagstaff, Arizona.


The author questions the survivability of an impacting body. He postulates that 1) craters formed by impacting events are dry, not lava-filled, 2) isostatic distortions occurred, but before this was complete, lava appeared from the body of the Moon and selectively filled the lower areas. This lava was denser than surrounding rock which presumably could have been more acidic, and 3) tension cracks (rilles) and compression fractures (wrinkle ridges) show that later subsidence and compression has occurred. Thus far only the dense material centered in craters and capable of yielding gravitational effects has been measured.
This report outlines the necessary requirements and constraints which would have to be met in order to put a Lunar Orbiter in an Earth-return trajectory around the farside of the Moon. This constitutes the basis of a contingency plan, should the Orbiter have failed to go into orbit around the Moon. During the fly-by the Orbiter could have taken useful photographs of the farside of the Moon. Upon return to the Earth the spacecraft would burn its remaining propellent to deboost into Earth orbit for readout of the data.


In studying existing spherical harmonic expansions of the Moon's gravitational potential and the difference among the lunar principal moments of inertia, the authors found two large gravitational anomalies not associated with those of Muller and Sjogren. One on the east limb of the Moon near Mare Marginis appears to be associated with a large circular basin, 900 kilometers in diameter, centered at 91 degrees east, 25 degrees north, with Mare Marginis filling in the southwest corner.

On the farside Lunar Orbiter photographs disclose what the authors feel is an enormous circular basin now very heavily eroded. The basin is 1,000 kilometers in diameter, centered at 173 degrees east, 11 degrees north. They propose that this be called Occultum (Hidden Basin).


Various theories exist about the origin of lunar sinuous rilles such as Schröter's Valley. The mechanism producing them can be categorized under aqueous erosion, faulting, and subsidence. Each of these does not stand the intensive investigations of the rilles' topography. Aqueous erosion is the least tenable of all the mechanisms because it necessitates the presence of very high vapor pressures for any liquid at lunar surface temperatures. Observable evidence speaks against faulting as the major mechanism causing rilles.
Igneous processes suggest another mechanism, but outflow of lava creates a raised feature, not a depression. Yet one process could explain their formation: nuées ardentes or fluidized outflows of gas-dust mixtures. The presence of sinuous rilles in the vicinity of craters whose formation seems to be volcanic, strongly suggests a relationship supporting this mechanism as the process by which these surface features have been formed.


Lunar Orbiter I photographs reveal portions of the Flamsteed Ring near the Surveyor I site. The convex body resembling a flow of viscous lava located near Apollo landing site A 9.2 at 2 degrees south latitude, 43 degrees west longitude has partially invaded nine craters in the area. This suggests that the flow material is younger than the mare material. The investigators conclude that these topographic features indicate the presence of extruded intermediate lavas of acidic composition. Such lavas are more viscous than basic lavas. The investigators further conclude that the Flamsteed Ring is not the result of basaltic flows despite lesser gravity on the Moon. These conclusions are preliminary.


The work of these two men shows that near-surface slab-like models produce anomalies of the magnitude observed from tracking data of the Lunar Orbiters. The authors assume that maria fill can be represented by a thin circular disk of dense rock at the lunar surface, imbedded in less dense material. Submarie and adjacent rim material has either lower density because this has been brecciated and pulverized by impact, or is a high density material if brought to the impact site by an impacting body.

This report concerns geological characteristics of the Moon, general composition, lunar geological processes, and cratering by possible cometary materials. Lunar Orbiter V photographs are used in the analysis of the craters Messier and Messier A.


Lunar Orbiter V photographs H-216 and H-217 of the Marius Hills constitute the basis for a geological survey which a manned roving vehicle could conduct during a five day period on the lunar surface. Included in this report are two large geological maps with scales of 1:200,000 and 1:25,000 respectively.


A new interpretation of lunar ring structures is the result of analysis of data from Lunar Orbiter and Surveyor. Instead of accepting the hypothesis that "elementary" rings represent old, partially filled craters, the authors posit the hypothesis that they are recent volcanic structures. Elementary ring structures occur mostly on flat, smooth floors of maria. They consist of lunaritic materials in hills or wrinkle ridges of both. The rings approximate circles or polygons and parts of them coincide in direction with local tectonic patterns. The rings are generally incomplete. The authors do not claim that all incomplete rings on the Moon have the same origins or are of the same type.


A Lunar Orbiter II photograph of an area in western Mare Tranquillitatis shows a boulder track down the wall of the crater Sabine D. Assuming a spherical boulder of \( r = 6.5 \) meters and a density of 3.0 grams/centimeter\(^3\), then the surface bearing strength is equal to 4 times \( 10^6 \) dyne/centimeter\(^2\) at a depth of 75 centimeters. This preliminary measurement is significant because it can be used as a lower limit of bearing strength over a length of 650 meters versus
the footpad-sized measurement of a landed spacecraft. The area of this measurement is also significant because it is a potential landing site for Apollo.


Firsoff discusses the implications of Lunar Orbiter photography in relation to two main theories about the formation of lunar surface features: water and volcanic/meteoric. The existence of sinuous rilles, of long valleys and evidences of "aprons" to the west and southwest of Tsiolkovsky suggest water action in various forms from high pressure sublimation to ash-covered glaciers. Many formations could not have resulted from lava flows as understood by known behavioral characteristics of such flows on Earth. Under conditions on the Moon lava cannot travel far. Water, however, when escaping to the surface under extreme pressure from within, could cause explosions and craters to form. Moreover, if one assumes that Orientale was formed in an asteroidal impact event, then this would have released sufficient gases and water trapped within to have formed a temporary lunar atmosphere. The impact would have triggered far-reaching processes and initiated prolonged volcanic activity whose effects would have affected the entire lunar surface.


Lunar Orbiter photography reveals closely spaced parallel lineament sets in such areas as the craters Gambart, Maske-lyne F, Gambart C, Kepler, and Copernicus, and also in Oceanus Procellarum and in Marius. These may be surface expressions of underlying faults or fractures. It is not certain if these lineament sets were restricted in formation to a single time span. Lineament sets parallel to polygonal sides or rayed and unrayed craters suggest the presence of a precra­ter parallel joint system. These surface lineaments may have been produced by Earth tidal forces. This would indicate that the Moon's surface is and has been a working unit through much of lunar history.

This report describes tests conducted to determine the usefulness of Lunar Orbiter photographic negatives in determining slopes on the Moon's surface. Random tests were conducted to define the reliability of film density measured against the gray scale. Results show that negatives with density readings higher than step nine of the gray scale give erroneous slope measurements.


Gilvarry posits the theory that positive and negative mascons have been caused by a series of events after the initial formation of the Moon: The lunar seas constitute the oldest exposed areas of the surface. Their presence and the existence of positive and negative gravitational anomalies in irregular maria rule out the lava mechanism formation theory and support the theory of a lunar hydrosphere at some time after the Moon's formation. Experiments with various soil types under conditions involving simulated lunar hydrosphere, atmosphere and vacuum conditions offer explanations for the nature of maria materials, the former existence of surface water acting as a transport mechanism for these materials, and the differing isostatic conditions between maria and highland areas. Negative mascons would have resulted when overlying water flowed to lower areas or escaped into space. The geographical location of negative mascons supports this supposition. Water, in turn, carried deposits down to the great circular maria whose depths, produced by meteoric impacts, accepted greater sedimentation and, therefore, increased mass concentrations.


The authors discuss the formation of the Tsiolkovsky crater on the farside of the Moon. They base their observations on data from Lunar Orbiter III high and medium resolution frames No. 121. Tsiolkovsky is a landmark on the farside, a young, distinct and very large crater in an area saturated with craters. The authors discuss the probably origins of Tsiolkovsky in relation to: 1) the distribution of craters around it, 2) the nature and shape of its rim, 3) radial gouges and crater chains, and 4) the presence of an apparent ejecta blanket. They conclude that Tsiolkovsky formed as a result of an impacting astroidal body or a giant volcanic explosion, and they prefer the former hypothesis to the latter.

All five Lunar Orbiters flew micrometeoroid flux experiments to test the frequency of micrometeoroid hits in the lunar environment. The only other spacecraft which had attempted to do this was the Soviet Luna 10. This spacecraft had registered particle impacts exceeding by two orders of magnitude the average of interplanetary space. The Lunar Orbiter experiments had a configuration which detracted from maximum exposure to the lunar environment. Test material onboard each spacecraft consisted of pressurized beryllium copper detectors covering an area of 0.282 square meters, of which only 0.186 square meters was effectively exposed. Over a one year period five Orbiters recorded a total of 22 hits or one-half the record registered in Earth orbit by Explorers 16 and 23, using the same kind of detectors. The investigators caution that these data are too tentative to form a general theory about micrometeoroid flux near the Moon.


Hartmann has examined rectified pictures from the Russian Zond III of portions of the Moon's farside and of Orientale Basin. He discusses the significance of the pictures in theories concerning the formation of lunar basins and the maria. Of special interest is Orientale which involves a whole system of craters, crater chains, concentric mountain rings and scarps including the Rook and Cordillera mountains. Photographic data is still too scarce to determine what role, if any, volcanism, tectonic activity, and ejected rubble played in modifying ancient continental uplands.


This brief article describes a flow-like surface feature in a farside crater some 70 kilometers south of Tsiolkovsky. Initial analysis of Lunar Orbiter photography indicates that the flow has a thickness of at least 20 meters at a point about 4 kilometers east of G in the superimposed schematic on the photograph. The author rules out the possibilities of it being a mudflow or an air-cushioned landslide because of vacuum conditions. He suggests that it is considerably more like an ash-flow tuff.

The authors conducted infrared studies of the Moon in eclipse on April 13, 1968, and their observations were the first to confirm the thermal anomalies observed by Saari and Shorthill in December 1964. They conclude that because the hundreds of anomalies have remained unchanged in 3.5 years, they are not the result of ephemeral activity on the lunar surface. They detected a linear thermal anomaly at the western edge of Mare Humorum which, unlike prominent crater anomalies, is warmer than its surroundings before sunset. It remains warmer after sunset. Lunar Orbiter IV photography of Mare Humorum, at a ground resolution of 54 meters, shows no unusual surface structures which would support the belief that the anomaly is caused by low thermal inertia material. The more probably cause is an internal heat source because 1) heat flow to the surface would make an area warmer than its surroundings during lunar afternoon, and 2) the geological position of the anomaly supports this.


The scientific objectives, operational guidelines and surface exploration constraints of a five-day mission of the Marius Hills constitute the subject of this report. Lunar Orbiter V photographs of this region have been used in constructing preliminary geological maps and descriptions of the traverses which astronauts could perform in a lunar roving vehicle.


The author discusses in detail the Lunar Orbiter photographic mission. Among its major tasks the Orbiter spacecraft is designed to obtain useful topographical data of the lunar surface for the Apollo Program. Special methods of photometric data reduction must be applied to Lunar Orbiter photography because of the peculiar characteristics of reflectivity of the lunar surface. Preflight calibrations will be necessary to compensate for any distortions in high resolution photography due to the Moon's surface characteristics and the fact that the film will not be returned to Earth.

The authors offer a summary of the various theories on the origins of the Moon and its shape and internal composition. They point out that no theory has explained the nature of the Moon's core nor the distribution of the density of subsurface material. They do not suggest the presence of mass concentrations (Mascons) on the Moon.


The report points out that there is a difference between the Moon's center of figure or volume and the center of its mass. There appears to be a systematic excess of elevation of continental areas over maria, relative to the Moon's center of mass. A comparison of the mascons with the lunar map indicates excess masses are concentrated within the inner rings of the Imbrium and Nectarae Basins. If mascons are assumed to be masses of nickel-iron, then they correspond to a layer about 12 kilometers thick. Isostatic models of the Moon also fit the data, but Lunar Orbiter data does not sufficiently resolve which model.


Ranger and Mariner software programs were found to be inadequate for Lunar Orbiter. Thus the Lunar Orbiter Program developed new concepts for flight control and the necessary software to implement them. Among other things the optimization of the midcourse aim point and the orbit injection point became a necessary and practical procedure. A mean element trajectory program was developed to facilitate orbital transfers by greatly reducing computation times to a few minutes rather than hours as was necessary under the special perturbation analysis approach.

The authors present a defense of the theory of water on the Moon as the major cause of sinuous rilles. Their analysis is based upon data from Lunar Orbiter IV photography and upon Urey's hypothesis of a lunar atmosphere existing at one time in the past. They point out that volcanic ash flows, as suggested by Gold, cannot explain the length and meandering of many rilles. Nor can faulting. However, water flow under a layer of surface ice offers a viable explanation. Moreover, certain events could have caused outgassing of major volatiles H₂O and CO₂. Major meteor impacts would have released trapped volatiles and could have led to a temporary atmosphere. They conclude that the distribution of sinuous rilles is the only available, unambiguous indicator of location of subsurface volatiles.


Lunar Orbiter photographs show sinuous rilles resembling meandrous channels of terrestrial streams. Thirty of these are visible from Earth. Lunar Orbiter revealed significant new features in the smaller meandrous channels inside the larger rilles. The authors hypothesize that the rilles are features caused by water erosion in the form of ice-covered rivers whose source is subsurface water released through the impacts of meteors.


The author describes the achievements of *Luna III* in 1959 and then compares them to the mission of *Zond III* in 1965. The latter confirms the data of the former concerning the lunar farside: it is more heavily cratered than the frontside. On the whole the craters exhibit similar features to those on the frontside. Crater chains also exist on the farside but are much longer, in some cases 1,500 kilometers. Numerous ring-shaped concavities called thalassoids also can be seen in *Zond III* pictures. In size and shape they compare to maria. No such thalassoids are present on the frontside. Lipskii concludes that available data show the Moon's surface to be continental with maria resulting from endogenic depressions being filled with lava.

MacDonald discusses the several modern theories concerning the nature and composition of the Moon's interior. He states that even a chemically homogeneous Moon would undergo discontinuities in the structure of subsurface material. Surface features and the lack of evidence of major faulting imply a constant volume of the Moon. Little conclusive evidence exists to prove or disprove current hypotheses. The author recommends that a lunar orbiter spacecraft circling the Moon could be tracked and that this would provide data on the Moon's gravitational field, its mean moment of inertia and other fundamental data which would reveal more about the nature of the Earth's natural satellite.


This report covers the results of orbit determination programs in the first four Orbiter missions. Orbit determination proved to be very accurate and precise with tolerable deviations from planned parameters. Some deviations between planned and executed midcourse, deboost, and orbit maneuvers resulted from oscillation in Doppler residuals, especially in low photographic orbits. Uncertainty of lunar gravitational constraints make orbital statistics not entirely valid. One accomplishment of the program was the improvement of orbit determination as a result of predicted photo-location by real-time and postflight orbit determination. On the Lunar Orbiter III mission the difference between the two factors was about 5 kilometers and considerably worse for certain sites in the first two missions.


The author points out that the Lunar Orbiter Program was by far the most productive of the precursor probes in terms of total amount of information received and the nature of that information in certain areas vital to further exploration. The author discusses several of the most significant topographical features which Lunar Orbiter photographed and concludes that the photographic data greatly help in identifying morphological classes of these features.

The authors summarize the mission of Lunar Orbiter and concentrate upon its usefulness in the more refined determination of the lunar gravitational field and the Moon's shape and mass. They briefly review the existing knowledge on these subjects and then describe in detail various technical approaches to the problem of determining spacecraft orbital parameters and what they will show about the Moon.


The authors have drawn preliminary conclusions about the significance of the orbital behavior of Lunar Orbiter I based upon early tracking data. Their primary task was the establishment of a rough estimate about the Moon's gravitational field from more extensive data from the other four Lunar Orbiter missions. Preliminary results of their investigation show that orbital variations during periods of photography did not degrade the quality of photographs. Tracking data used in this analysis were two-way Doppler data providing a measure of relative velocity of the spacecraft and the NASA Deep Space Network stations in California, Spain, and Australia.


The investigators have used ranging residuals data from the first two Orbiter missions to test corrections in the lunar ephemeris. Most residuals were reduced to less than 100 meters. Preliminary ephemeris tapes at the Jet Propulsion Laboratory were used to analyse raw data. Tracking data from the Deep Space Network stations enabled the investigators to refine the mathematical calculations. Variations in ranging residuals from the three stations verify unusual Doppler residuals obtained near pericenter passage of Lunar Orbiter I. These were not attributed to onboard systems anomalies and appeared to be real and to show that the spacecraft had an anomalous motion of 60 meters near pericenter.

The authors have analysed the results of Earth-based coherent two-way radio Doppler data from the Lunar Orbiters. They found the residuals consistency to be too high. This could be caused by: 1) forces such as gravity, solar pressure, gas jets, 2) errors in tracking data, and 3) software problems in the computer. They then utilized higher harmonics models of the Moon, and the residuals reduce, reaching agreement between separated flight on the same trajectory.


The authors have constructed a gravipotential map of the nearside of the Moon based upon orbital accelerations of the Lunar Orbiter spacecraft. These show gravitational anomalies termed "mascons" beneath the lunar surface in all five of the ringed maria. This suggests a correlation between mass anomalies and the ringed maria. Conclusions are tentative.


A brief description of the Lunar Orbiter Program's history, this report describes the spacecraft, its mission, and what the first Lunar Orbiter accomplished.


Norman discusses the Apollo requirements for cartographic and topographic data on the lunar surface, the landing sites and their approaches. Photogrammetry plays a mandatory role in determining accurate coordinates for landing sites and reference marks called landing-site landmarks. Lunar Orbiter photographic data has provided the only applicable source for making large scale maps of the Apollo landing zone. How this is done constitutes the subject of the article. The author concludes that Lunar Orbiter successfully demonstrated the potential of surveying and mapping the Moon or a planet from space.
Analyses of Lunar Orbiter I photographs of Oceanus Procellarum showing craters of varying morphology indicate a correlation between crater size and crater shape as a result of meteorite impact against a surface consisting of fragmental material of varying thicknesses overlying cohesive substrata. The analysis of these data indicates that 85% of the area considered has surface thickness between 5 and 15 meters. Photographs from Luna 9 and Surveyor 1 support this indication. Moreover, formation of new rock surfaces appears to have occurred intermittently, leading to a complex stratigraphic sequence of alternating hard and fragmented rock. The existence of concentric craters substantiates this sequence.

The distribution of the lunar regolith thickness for twelve areas on the Moon has been determined using high resolution photographs from Lunar Orbiters II, III, and V. All but one area lie within ten degrees of the equator. The exception is in Mare Imbrium. The article compares lunar crater geometry with laboratory craters. Results show that the regolith thickness varied from 3.3 meters in the southern portion of Oceanus Procellarum to 16 meters in the crater Hipparchus. The report also discusses the delineation of flow fronts and the discovery of many linear markings on the presumed flows. These lineaments may be crater chains of a collapsed or drainage origin. Still other lineaments may be lava channels. The authors conclude that the thickness of the regolith is a function of crater density. Over time impacting bodies break down the lunar surface and create the regolith which is the result of impact fragmentation.

This report describes a system for determining the relative age of craters on the lunar surface by using as a basis
their major topographical components. From this the authors have constructed a preliminary morphological continuum which they use to classify craters over the entire surface of the Moon. Lunar Orbiter photography was instrumental in providing them with reliable data.


The photometric method for deriving surface elevations from a single picture of the lunar surface in the absence of stereoscopic pictures is described. The author uses Ranger photographs as subjects and concludes that a derivation of quantitative topographic information about an object scene is possible. At best the resulting data are indirect, and estimation of errors seems unrealistic by analytical means. Moreover, calculations show that it is wrong to assume uniform albedo for large areas.


Photography from Lunar Orbiter III, a topographic map of the Surveyor III landing site, and photographs from Rangers VIII and IX are utilized in applications of the power spectral density (PSD) function to determine relative roughness of different types of lunar terrain. Such information would be valuable in the construction and operation of a lunar roving vehicle.


Scherer describes the Lunar Orbiter spacecraft as a platform designed to carry a camera system which can take high and medium resolution photographs of the Moon's surface. The spacecraft has four objectives: 1) obtain photography of wide areas of the Moon to certify Apollo and Surveyor landing sites, 2) define gravitational field of the Moon through refined tracking of the spacecraft, 3) measure micrometeoroid and radiation flux during extended lifetime of spacecraft, and 4) provide a spacecraft for equipment checkout and personnel training of the Apollo tracking network.

The author bases his interpretation on impact studies of steel projectiles into concrete and soils and then makes large extrapolations upward in size. On the Moon an impacting body must penetrate below the surface to a depth of 290 kilometers before pressure can be released sufficient to melt material. His results suggest that lava-filled maria formed when large iron objects struck the lunar surface at a velocity so low that there was no immediate fracture of the object. The impact produced a large crater and material flowed to the surface to fill the crater. Each mare was formed by one large iron object impacting, and the remnants of this dense object under the mare are the mascon.


Swann describes how investigation of the Moon's surface can test the hypotheses based upon terrestrial observations of the geological history of the Earth in an effort to determine the origins of both bodies. The Apollo system constitutes the basic capability with which such extended lunar exploration can be carried out.


The first three Lunar Orbiter spacecraft photographed 8% (600,000 square kilometers) of the nearside of the Moon. High resolution photographs show that the surface is dotted with a great number of small, perfectly circular craters from 50 meters diameter down to the limit of resolution. The majority of these are cup-shaped with distinctly sharp rims. But many also have shallow interiors and indistinct rims. The authors conclude that these craters were formed by primary and secondary impacts. Fresh craters are those which have material on the exterior slopes which is distinctly different from adjacent material of the inter-crater areas. These young craters also tend to have a profusion of angular blocks on the floors and exterior slopes. The albedo of these blocks and other ejecta material is relatively high. The number of fresh craters is much less than the number of craters not exhibiting these features.

Lunar Orbiter I bounced continuous wave signals off of the Moon's surface, and these were received on Earth. Using the frequency spectrum and studying Doppler shifts, the investigators located discrete, heterogeneous scattering centers on the lunar surface. Shadowing, especially within five degrees of the terminator would effectively "hide" some scattering centers. On the other hand variations in surface reflectivity provide a model which will explain the observations. This could mean that material in scattering areas is considerably more compact or different from material in surrounding areas. The use of continuous-wave bistatic radar appears to offer a new method for mapping and study of lunar and planetary surfaces.


This two-part report discusses some of the problems inherent in an extended lunar surface mission in the Orientale region and the scientific points of interest which such a mission might best help to explore. Lunar Orbiter photography played a significant role in the preparation of this report, The authors discuss various arguments about the origins of Orientale and the geological features which would be most significant in a surface investigation.


The Moon has a viscosity higher than that of Earth by a factor of $10^4$. Mascons represent a non-isostatic condition in the surface of the Moon. Apparently an object collided with the Moon's surface, flattened out and left high density material that has remained since the maria were formed. Lava flows cannot account for what is observed on the Moon. Maria areas on the Moon are not lava flows, and no liquid masses exist below the Moon. Thus large objects collided with the Moon in its early history. These objects should be similar to meteorites in composition and density. Finally, the Moon has sufficient rigidity to support these masses.

Urey summarizes several arguments against the presence of water on the Moon, and then he presents his own detailed argument, based upon his knowledge and new data from Lunar Orbiter photographs, in support of the presence of water on the Moon. The existence of rilles and of such landmarks as Schröter's Valley, the irregularities of the crater Krieger north of Aristarchus, and the knowledge of terrestrial geological processes causing pingos in areas of permafrost strongly support the theory that water has existed on the Moon and has caused various lunar surface formations. Urey defends the view that water, not lava or dust-gas mixtures, formed the maria and that these may yet be frozen seas. However, he concludes that this in no way defines the composition of the solid materials in the maria.


This report, done under contract to NASA, explains the usefulness of stereoscopic photography transmitted to Earth by Lunar Orbiters II, III, and V in mapping the Moon. High resolution stereo photographs include coverage otherwise unobtainable from a vertical mode. Moreover, the exaggerated height effects in convergent stereo photography should increase the accuracy in the determination of ground point elevations. The report discusses the problems of using existing computer programs and available photographic data for convergent photo triangulation. It also outlines the best methods for accomplishing triangulation. Tests with Lunar Orbiter data proved that accuracy of triangulation is increased by using high resolution stereo photographs.

SECONDARY LITERATURE -- PART II


ORGANIZATION CHARTS
Overall Project Management Organization for Lunar Orbiter

*Explanation Key to this chart is found on the next page.
Explanation Key

NASA Administrator: James E. Webb
Assoc. Administrator: Dr. Robert C. Seamans, Jr.
OART: Office of Advanced Research and Technology
OSSA: Office of Space Science and Applications
OMSF: Office of Manned Space Flight
OLPP: Office of Lunar and Planetary Programs
LOPO: Lunar Orbiter Program Office

LRC: Langley Research Center
LeRC: Lewis Research Center
JPL: Jet Propulsion Laboratory
KSC: Kennedy Space Center

LOPO: Lunar Orbiter Project Office, Manager
Mission Sys. Int.: Mission Systems Integration
S/C Mgr. LRC: Spacecraft Manager, Langley Research Center
L/V Mgr. LeRC: Launch Vehicle Manager, Lewis Research Center
Opm's Mgr. LRC: Operations Manager, Langley Research Center
DSN Mgr. JPL: Deep Space Network Manager, Jet Propulsion Laboratory

Boeing: The Boeing Company, Seattle Washington (Prime Contractor)
L/V: Launch Vehicle
S/C: Spacecraft
ULO: Unmanned Launch Operations
DSIF Sites: Deep Space Instrumentation Facility Sites
SFOF: Space Flight Operations Facility
RCA: Radio Corporation of America, Princeton, N.J. (Subcontractor)
Eastman Kodak: Rochester, N.Y. (Subcontractor)
AF SSD: Air Force Support Services Division
Veh. &S/C Sup.: Vehicle and Spacecraft Support
Agena Opsns.: Agena Operations
Range Opsns.: Range Operations

LMSC Agena: Lockheed Missiles and Space Company, Contractor for Agena
GD/C Launch: General Dynamics, Convair Division, Contractor for Atlas
GE: General Electric (Subcontractor)
Burroughs: (Subcontractor)
Rocketdyne: (Subcontractor)
Langley Lunar Orbiter Project Office Functional Staff Organization.