DECLASSIFIED UNDER AUTHORITY OF THE
INTERAGENCY SECURITY CLASSIFICATION APPEALS PANEL,
E.O. 13526, SECTION 5.3(b)(3)

ISCAP APPEAL NO. 2009-068, document no. 3
DECLASSIFICATION DATE: November 13, 2014

AFMDC-TR-63-2
Technical Report

~~SECRET~~

SPECIAL HANDLING REQUIRED; NOT RELEASABLE TO FOREIGN NATIONALS.
The information contained in this document will not be disclosed to Foreign Nationals or their Representatives.

(U) LUNAR EXPLORATION SYSTEM SPACECRAFT CONTROL

SEPTEMBER 1963

TASKS 618207(66)
618207(74)

AIR FORCE MISSILE DEVELOPMENT CENTER

DEPUTY FOR FOREIGN TECHNOLOGY

AIR FORCE SYSTEMS COMMAND

HOLLOMAN AIR FORCE BASE

NEW MEXICO

~~GROUP-1~~
~~EXCLUDED FROM AUTOMATIC DOWNGRADING AND DECLASSIFICATION.~~

EXCLUDED FROM GDS

~~SECRET~~

AFMDC 63-4453
COPY NR 37

(This page is unclassified)

0 6 1 6

1. Information conflicting with or pertinently affecting that contained in this publication should be forwarded by the recipient directly to:

AFMDC (MDFB)
Holloman AFB, New Mexico 88330

This in no way abbrogates or alters responsibility for sending such information or any pertinent intelligence data through already established intelligence collection channels of the various services or agencies of the U.S. Government.

2. WARNING: This document contains information affecting the national defense of the U.S. within the meaning of the Espionage Law, Title 18, U.S.C., Sections 793 and 794. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

3. Copies have not been placed in the DDC collection. Address all requests for copies to AFMDC (MDFC).

4. Do not return this copy. When not needed, destroy in accordance with pertinent security regulations.

5. This publication has been designed to meet the specific needs of the recipient for intelligence. Further dissemination by the recipient of parts or the whole to subordinate elements must be based on the specific need-to-know of the recipient to perform his assigned missions. (Authority: AFCIN Policy Letter 205 5 dated 20 February 1959)

SECRET

FOREIGN TECHNOLOGY REPORT

AFMDC-TR-63-2

(Title Unclassified)

LUNAR EXPLORATION SYSTEM SPACECRAFT CONTROL

September 1963

(Cutoff Date: 27 September 1963)

Task 618207(66)
Task 618207(74)

Prepared by:

Captain James E. Howard

This is a Foreign Technology document prepared and published by AFMDC for use primarily within AFSC. It has not been coordinated within AFSC or the Office of the ACS/Intelligence, Headquarters USAF, and does not necessarily represent an agreed Air Force position.

Special Handling Required; Not Releasable to Foreign Nationals. The information contained in this document will not be disclosed to Foreign Nationals or their representatives.

Group-
Excluded from Automatic
Downgrading and Declas-
sification

DEPUTY FOR FOREIGN TECHNOLOGY
AIR FORCE MISSILE DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
HOLLOMAN AIR FORCE BASE, NEW MEXICO

SECRET

(This page is unclassified) AFMDC 63-4453

PREFACE

In the course of preparing this report, it became obvious that there exist many individual definitions of exactly what functions constitute stabilization, attitude control, guidance, and navigation when these terms are applied to a space vehicle. To avoid confusion, the following definitions are used in this study:

Stabilization refers to the inherent ability of a properly designed spacecraft to maintain an established attitude in the presence of perturbing torques. This function is more properly called passive attitude control and makes use of external forces due to gravity gradients, aerodynamic interaction, radiation pressure, or spin to provide stability.

Attitude control refers to the utilization of spacecraft generated forces to maintain, or assume, a prescribed attitude in space. This function includes sensing, control moment production, and the necessary devices to provide stable operation.

Guidance consists of determining the present position and velocity of the space vehicle during powered flight and of generating steering and thrust shutoff commands which will cause the vehicle to achieve satisfactory burnout conditions. It is most simply control of the translational movement of the vehicle.

Navigation is the determination of the position of a space vehicle, usually with respect to celestial references.

PUBLICATION REVIEW

This Foreign Technology document has been reviewed and is approved for distribution within the Air Force Systems Command.

FOR THE COMMANDER

Howard L Conkey
HOWARD L. CONKEY
Lt Col, USAF
Deputy for Foreign Technology

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECRET

(U) SUMMARY

Purpose

This report presents the results of analysis initiated to satisfy Tasks 618207(66 and 74) of the SPAO SLEPTOPS on Soviet Lunar Exploration System Spacecraft Stabilization, Control, Guidance, and Navigation Equipment. (S)

Conclusions

The following are the postulated pertinent characteristics of the SL-2 spacecraft systems:

a. The Lunik IV spacecraft was a nonspinning, inertially oriented vehicle. Sun finders and precise sun seekers were used to align the roll axis and provide orientation for solar cells; an earth sensor was utilized to provide roll attitude and alignment of a communications antenna. Control torques were generated by a cold gas actuation system, and no passive attitude control (stabilization) was designed into the vehicle.

b. The required trajectory information and midcourse correction were ground computed from tracking data. The midcourse maneuver was not successfully accomplished. No on-board navigation or computation equipment was utilized.

c. The most probable midcourse guidance system was a simple autopilot-velocity meter scheme, utilizing three rate gyros and an integrating accelerometer. This same system could have also been used for injection guidance once the required attitude had been established during the parking orbit from a reference external to the spacecraft. The sun was available and is the most likely choice based on the demonstrated Soviet preference for this reference.

d. The lunar descent reference (if soft landing or near orbit was the intended Lunar IV mission) would be based on specialized radar measurements.

e. The SL-2 series shows that the Soviets cannot, at this time, accomplish high accuracy lunar missions with any degree of reliability. The basic difficulty may well be control associated. (S)

Background Highlights

This report was prepared from extensive Soviet open source literature, Foreign Technology studies on Soviet spacecraft control, U.S. technical studies on guidance and control, and available [redacted] studies. Since a lack of definitive data existed for the SL-2 series, postulations made are based mainly on the capabilities demonstrated in the SL-1 series and

50X1 and 3, E.O.13526

the deep space probes, constrained by current and projected U.S. technology. (S)

Discussion

See Section I. (U)

~~SECRET~~

SECTION 1

(U) INTRODUCTION

The design of an attitude control system for a satellite or a space probe is necessarily dictated by the mission requirements of the spacecraft. For this reason, the requirements must be well defined and understood before any meaningful analysis can be undertaken. Also, in general, there is no unique choice among the various feasible sensing and actuation combinations which "best" satisfies the performance requirements of a particular mission. More often the designer is forced to select tentative systems, conduct a trade-off study, and base final scheme selection on the results of this experimental approach. (U)

This lack of existence of an easily identifiable optimum system compounds the analysis problem. On the one hand there is the natural tendency to seek the simplest mechanization (consistent with the external signature) because of the Soviets' penchant for simplicity. On the other hand systems must be examined for future potential, which is usually equated to accuracy and versatility; and these qualities are not synonymous with simplicity. In an attempt to overcome this inconsistency, this study will:

a. Describe the attitude control requirements for a hypothetical soft lunar landing vehicle launched from a parking orbit.

b. Enumerate some open source Soviet technical studies which are pertinent to the control problems of lunar flights.

c. Examine previous Soviet space probes (SL-1 and Venik) to assess their implications on future lunar control system capabilities.

d. Analyze all existing data on SL-2 launches to find a correspondence with either the studies in paragraph c above or existing/proposed U.S. schemes.

It is believed that this method insures the most logical approach to the problem and should provide answers with good validity. (S)

A basic shortcoming in this study must, however, be pointed out. At the cutoff date, very little data on the SL-2 series was available for analysis. Neither Soviet open source descriptions of Lunik IV nor any [redacted] Because of this lack, the study is mainly limited to those capabilities and potentialities demonstrated by earlier space probes, and the latest of those was launched more than two years ago. This lack of

50X1 and 3, E.O.13526

2009-068
Document 3

BB 115 – Part 1

Missing page 3

SECRET

SECTION II

(U) LUNAR FLIGHT CONTROL REQUIREMENTS

For a lunar ascent from a parking orbit, active attitude control begins at termination of third stage burning. At this time the fourth stage and probe are spinning, usually about an arbitrary axis at an unpredictable rate (as high as 1,000 to 10,000 degrees/hour in some U.S. spacecraft). This angular disorientation, which occurs from anomalies in third stage burning and separation, must be corrected to allow orientation for injection into the lunar orbit. Thus the control system must sense the unwanted rotation and cause restoring torques to be applied in order to orient the vehicle to the desired parking orbit attitude. The rotations can easily be sensed by rate gyros mounted along three arbitrary spacecraft axes. These gyros then provide actuation of the restoring force producers resulting in torques which reduce the spin rate to zero. This action requires high level torques which can only be provided by a mass expulsion actuation scheme. (S)

U.S. studies have found that the simplest, lightest, and most reliable mass expulsion actuator system for lunar flights utilizes cold-gas, usually dry nitrogen. The system requires a

2009-068
Document 3

BB 115 – Part 1

Missing page 5

The exact injection orientation and time of injection required are predicated on the launch time and, to a lesser extent, the parking orbit attained. These constraints, as it turns out, are insensitive to variations in the parking orbit about nominal. This is a fortunate circumstance since the tracking limitations inherent in the use of a coasting phase do not allow precise parking orbit determination; the position and velocity of the spacecraft at any particular instant cannot be predicted as exactly as would be desired. For example, it is estimated that an uncertainty of 2 nautical miles along each axis in position and 3-5 fps in velocity existed at the injection of Lunik IV. Errors of this magnitude are not overriding; but propagated to lunar distances, they can result in unacceptable miss distances for sophisticated missions. (S)

At initiation of the injection stage, control requirements undergo a drastic revision. The control system must then perform the missile autopilot function during the burning phase. The standard components to provide this function are contained in the injection stage, and thus are not strictly spacecraft associated. It is important at this point to distinguish between guidance and control. The guidance problem (in the Soviet sense) consists of determining the present position and velocity of the vehicle, comparing these quantities with the nominal, and generating steering and engine shutoff commands which cause the vehicle to achieve the nominal burnout conditions. The control system problem is to mechanize accurately the steering commands so as to get the response demanded by the guidance system. (S)

Many problems arise in attempting to perform the guidance function during injection into a lunar ascent trajectory from a parking orbit. Radio guidance is not generally feasible because of the variety of injection locations required for optimizing the lunar launches on different dates. The use of inertial components results in large errors because of the gyro drifts encountered in long coasting orbits, which, in turn, seriously degrades the accuracy of the injection phase. Thus, at least two unrelated and serious error sources exist at injection which reduce the accuracy of this maneuver below the acceptable limits for either lunar impact or close lunar orbit. To correct these errors, it becomes necessary to include a post-injection correction in the transfer orbit. For this reason it is believed that any lunar mission injected from a parking orbit must have a midcourse correction included in its program. (S)

Although this correction capability complicates spacecraft design, it simplifies the guidance requirements for the injection stage. It has been found that the use of a simple autopilot-integrating accelerometer system adds very little to the velocity requirements for the midcourse correction. In this scheme the control system of the injection stage would merely maintain the nominal injection attitude established by the spacecraft control system, and an integrating accelerometer would terminate thrust at the required velocity as determined on the ground from the parking orbit tracking data. (S)

Following the injection into the transfer orbit, the de-spin process must again be accomplished using rate gyro outputs to initiate the stabilizing torques. As the arbitrary spin rate is reduced to near zero, the sensors which are used for attitude measurements during free flight begin to acquire their references. This acquisition period is, in general, not time limited; and there is no stringent requirement for large control forces. (U)

The sensors which can establish the required space orientation are many; and as indicated before, there is not necessarily an optimum choice. However, since solar paddles are probably a necessity, the sun is a most likely reference for attitude sensing. In the most general mechanization several sun seekers positioned strategically about the spacecraft serve to provide initial acquisition, with fine alignment provided by precise sun sensors. These sensors act to point the spacecraft roll axis to the sun, thus establishing the direction of a line in space and providing attitude orientation in both pitch and yaw. (U)

The reference for the remaining stability axis, roll, can be provided by either the earth or some "fixed" star. The selection of a fixed star allows greater system versatility since the geometrical relationships of the earth-sun-moon can, in some instances, preclude the use of the earth as a reference. A requirement probably exists, though, for fairly precise pointing of a high gain communications antenna to the earth which can most simply be accomplished by an earth sensor. Also, little generality is lost by this selection of reference. Since the spacecraft has been aligned on the sun, acquisition of the earth reference is a simple process. The location of the earth with respect to the roll axis which is aligned to the sun can be easily predicted. The sensor is then simply offset from the roll axis some predicted amount and the vehicle is rolled until the sensor acquires its reference. As soon as lock-on is accomplished, the spacecraft is oriented in all three axes and the attitude is established. At the same time both the earth and sun positions are known relative to the spacecraft, and orientation information for both the solar cells and a communication antenna is readily available. The actual orientation method is again an intimate function of design. (U)

At the completion of this acquisition phase, a cruise mode is entered. This is a period of passive flight when the primary function of the spacecraft is to simply travel from one point to another under its own momentum. The attitude control system requirements are very different in this mode of operation. During the acquisition and orientation modes, both gyroscopic and celestial references may be required, whereas during this cruise mode only celestial (earth, sun) references are needed. Also because of the small perturbative torques present on a properly designed spacecraft during cruise, a smaller capacity control actuation scheme is feasible; momentum storage through the use of reaction wheels can provide adequate control moments. As an extreme, it might be possible to eliminate all attitude control during this period. The solar panel and communications antenna orientation requirements, however, generally preclude such complete removal of active control. (U)

During the cruise phase, deviations from the desired attitude are sensed by the sun sensors in pitch and yaw and the earth sensor in roll. These sensors provide angular position errors to the control logic circuitry which in turn initiates control pulses (either through mass expulsion or momentum storage) to return the spacecraft to the desired orientation. The actual errors which are accepted during this mode are a function of design of the circuitry (deadband) from considerations of control torque capacity of the system. If a low capacity actuator system is employed, the deadband may be fairly large. This is rather a moot point, however, there being no stringent requirement for extreme accuracy during this coasting period unless scientific experiments are being performed which require precise pointing of the spacecraft. (U)

The angular rate signals necessary for system stability in this mode can be obtained directly from the rate gyros or derived from the switching amplifier output. If it were desired not to run the gyros constantly due to lifetime limitations, the derived rate would be used and the gyros operated only during active periods. (U)

After a cruise period of 15 to 20 hours, the spacecraft is ready to execute the midcourse maneuver. The actual timing of this maneuver is derived from the ground based tracking information which determines the required correction to the trajectory. In general, errors in velocity are best corrected early in the flight; and angular errors, late in the flight. A midcourse maneuver command is transmitted to the spacecraft and stored in on-board memory device. This stored command contains four items of information: the magnitudes and directions of the rotations about the pitch and roll axes required to correctly align the vehicle fixed thrust vector, the time of thrust initiation, and the magnitude of the velocity gain required. The velocity increment can be controlled by an integrated accelerometer output which generates a shutoff signal for the midcourse rocket, or a timed burning period. (U)

This commanded orientation, through the rate gyros, must originate from a precise reference to achieve the required orientation accuracy. Thus, the positional accuracy derived from the sensors must be on the order of 0.2 degrees in all axes to achieve lunar impact. This accuracy requires the attitude control system to suspend the cruise mode prior to midcourse correction and to accomplish the precise pointing necessary. Failure to achieve the required pointing accuracy can result in an increase in miss distance (viz. Ranger 5). At initiation of the midcourse orientation the sensors are removed from the attitude system and the rate gyros provide the attitude reference. Since the control actuation system has insufficient capacity to overcome any error torques developed by the midcourse rocket jet exhaust vanes or gimbaled engines must be employed to provide attitude control during this thrusting period. This requires standard autopilot electronics using gyro derived error signals and actuator positions for stability of operation. (C)

At the completion of the midcourse maneuver, the sun and earth are reacquired by repeating the same process associated with initial acquisition. The spacecraft then enters a second cruise period with the same characteristics as the previous one. This mode is continued until near lunar approach at which time further maneuvers are a function of the particular mission of the spacecraft. For this treatment, lunar soft landing will be assumed as the goal of the flight. (U)

At about 1,000 miles from the lunar surface, the ground commanded reorientation for final descent is begun. The roll axis, which was aligned with the sun in the cruise mode, is programmed through the rate gyros to orient approximately along the velocity vector expected for the time of retro ignition. Attitude sensing could then be transferred to horizon seekers for precise alignment of the roll axis with the local lunar vertical. Because of the precise navigation and guidance requirements for the soft landing, certain procedures must take place at this time. The first change occurs because of the long transmission delay which exists at lunar range. This delay makes it necessary to switch from ground command to a programmed inertial and radar control. Also the operation of specialized radars must be initiated to determine attitude, vertical, and lateral velocities. These radar derived measurements control both vehicle attitude and retrorocket operation, causing the spacecraft to follow a programmed trajectory to landing. (U)

This description provides, in a general manner, the control, navigation, and guidance requirements for a lunar soft landing vehicle injected from a parking orbit. The details for each separate discrete operation are not intended to constitute the only, or even the best, possible mechanization for each action. They are, however, probably the simplest ways and do provide a basis for further analysis of operational schemes. (U)

SECTION III

(U) SOVIET TECHNICAL LITERATURE

A search has been initiated in the available open source Soviet technical literature to find reports applicable to the lunar control requirements. There are numerous technical articles on the theory of optimum control systems which have indirect application to this area. These studies, in essence, are directed to the goal of obtaining the best control for the least expenditure of weight of components. The exact applicability of these studies is difficult to assess since all are couched in pure mathematical terms and notation. They do indicate an extensive interest in optimization and make the use of a highly optimized system probable. ~~(S)~~

A study applicable to cruise mode attitude control is "Some Guidance Problems in Interplanetary Space" by B. V. Raushenbach and E. N. Tokar, translated from Artificial Earth Satellites, 1960, Nr 5. This is a textbook examination of attitude control through momentum storage in inertia wheels. No mechanization is proposed, nor is any mention made of practical applications other than through inference. It does provide, however, the type of theoretical base from which design could grow. ~~(S)~~

An extremely sophisticated approach to attitude control and navigation is presented by V. A. Bodner and V. P. Seleznev in "Theory of Three-Axis Stable Systems Employing External Information," *Izvestiia Akademii Nauk SSSR, Otdel Tekh Nauk, Energetika i Automatika*, 1960, Nr 3. This paper presents a highly mathematical approach to a combined astro-inertial system utilizing an inertial platform, three accelerometers, and three tracking telescopes. A complete error analysis is performed using an earth orbit as a reference. A system of this type provides a very precise attitude control and also can perform both guidance and navigation functions. A scheme of this complexity has little application in the present time period but will probably become a necessity in the more sophisticated lunar missions of the future. (S)

A possible application of a system of this type would be to provide inertial references for precise guidance and control of the spacecraft during the injection to transfer orbit and during midcourse corrections. This is a highly complicated system with attendant low reliability, but it does provide better accuracies than possible with a less sophisticated scheme. (S)

The same system was presented by Seleznev in an article entitled "Space Navigation" which appeared in the Nr 2, 1962, issue of Aviation and Cosmonautics. This treatment omitted the mathematical detail and presented the idea of astro-inertial navigation in laymen's terminology. (U)

Both of these articles show a schematic of a possible mechanization of the system, discuss computer requirements, and point out the necessity of a precise time measurement. The extreme complexity of the system is stressed in both articles. (U)

Although none of these articles are strictly applicable to the Soviet lunar missions which have been so far performed, they do indicate that much serious work is being expended in solving the attitude control requirements of future, more complex deep space flights. (U)

SECRET

SECTION IV

(U) SPACE PROBES

FTD-TT-62-121 provides general detail on the flights of Luniks II and III from which certain observations about the attitude control system can be deduced. This document, which is a translation of selected articles from Soviet Satellites and Space Ships by S. G. Aleksandrov and R. Ye. Federov, substantiates the statements made earlier by both Sedov and Blagonarov, and adds considerably to the detail of the earlier Luniks. (U)

The authors describe the basic elements of the Lunik III control system as:

a. Optical "feelers" (solar and lunar).

b. Gyroscopic "feelers."

c. Electronic logic circuits.

d. Control motors (identified as cold-gas jets by Blagonarov).

In this probe, power for operation of the electronic subsystems was provided by both solar panels and a storage battery. Discrete operations were initiated by ground commands with functions performed near the lunar surface preprogrammed in the logic circuitry. ("Autonomous" control was undoubtedly necessary near the moon because of the transmission delays encountered in using ground commands). (8)

Lunik III was injected on a direct ascent and no midcourse correction was made; the spacecraft flew in the previously described cruise mode from injection to near lunar approach. No active control was exercised during this period; inertial stabilization was provided by spin about the longitudinal spacecraft axis. Although no mention was made in any account that this inertial orientation was stabilized along the velocity vector at injection, this postulation is made for the following reason: High noise levels in radio transmissions from lunar distances made it almost a necessity for a spacecraft antenna to be nominally pointed at the earth. There is no mention made (nor any indication from photography of the probe) that such a steerable antenna was employed or that an earth sensor was aboard which could orient the spacecraft and point an antenna. Because of the high injection velocity, however, the earth-moon trajectory was essentially a straight line and an inertial orientation as described above would provide a near alignment to the earth throughout flight within the earth's sphere of influence. The spin stabilization also served to control spacecraft heating and, in conjunction with the solar panels mounted around the circumference of the spacecraft, removed the necessity for orientation on the sun to insure proper operation of the solar power supply. (S)

Although the listing of basic control elements contained gyroscopic "feelers," no mention is made of their employment in the report. Since a yaw gyroscope is not feasible in this application, and an inertial platform is unnecessarily complex, these feelers were undoubtedly rate gyros, used as described previously for the immediate post-injection orientation and other functions later in the flight. (S)

Thus, it is established that the orientation during the cruise mode was inertial and was a result of a spin imparted about the longitudinal axis. The completely symmetrical configuration of the spacecraft about the long (roll) axis confirms the use of spin stabilization. (S)

The first requirement for active control of Lunik III attitude after injection occurred as the probe approached the lunar surface. It then became necessary to reorient to permit moon photography. This reorientation was simplified by the geometry of the sun-moon combination; upon near approach the probe lay approximately on a straight line joining the sun and the moon, and permitted approximate moon acquisition simply by pointing the appropriate spacecraft axis to the sun. (See Fig. 1.) (U)

Before the required reorientation could occur, the spacecraft had to be de-spun. Information derived from the rate gyros actuating the cold-gas jets provided the control torques necessary. The command to de-spin was undoubtedly ground originated; all subsequent actions were preprogrammed and stored in the logic circuitry. After completion of the de-spin process, attitude sensing was switched to sun finders. These finders, which were positioned around the spacecraft, indicated the general location of the sun and provided signals to grossly align the longitudinal axis on the sun. As the axis approached the sun, more accurate sun seekers then locked onto the sun, providing precise alignment and at the same time stabilizing both the roll and yaw axes. When this lock-on occurred, the roll axis was also approximately pointed to the moon because of the unique geometry mentioned previously. Control sensing was then switched to the moon sensor which acquired and locked on the moon, thus establishing a reference for the photography which followed. (S)

Certain deductions as to sensing techniques and sensors employed can be made from the described and hypothesized lunar

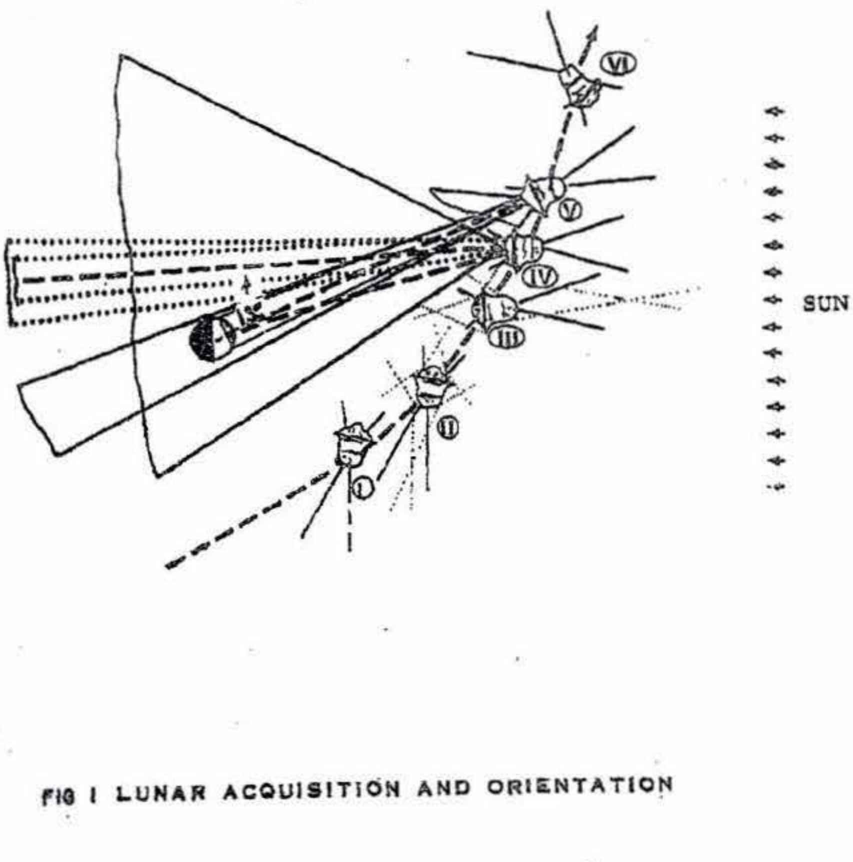


FIG I LUNAR ACQUISITION AND ORIENTATION

orientation. The primary alignment which required a sun reference indicates that the Soviets could not predict with sufficient certainty the location of the moon relative to the longitudinal axis of the probe at its nearest passage. The use of the sun with its high prominence in any spectral region allows a very simple search technique; it is performed by the dispersion of sensors on the spacecraft body to provide a spherical field of view. This is the simplest method (and the most reliable) for approximate orientation to the desired attitude. A simple mechanization using cadmium selenide detectors could provide center pointing of the sun and would be well within the necessary accuracy requirements. (S)

Since the sun lock-on provided an approximate lunar point under the geometry which existed for Lunik III, no mechanical scan was required for the moon sensor in its acquisition phase. It could most simply be an optical device with approximately a 30° field of view. By concentrating the energy reflected from the moon onto an appropriate detector, the spacecraft could be controlled to orient itself to the center of the radiative source. In a simple mechanization, the detector could consist of a quadrant mosaic arrangement of sensitive detectors with some type of shadow shield above them. Any alignment of th:

axis of the shadow shield to other than the target results in a differential detector output which can be used to drive the body-fixed shadow shield, and hence the spacecraft, to align itself with the target source. The alignment, in this case, provided approximate local lunar vertical sensing. This mechanization is essentially a sun sensor and does not have general application to lunar and planetary sensing. (S)

Again the geometry of the sun-moon combination makes this simple and reliable mechanization possible. The limitation of the technique described above when applied to sources other than the sun arises because these bodies do not radiate, but merely reflect incident sunlight. Thus if the target face presented to the sensor is not fully illuminated, the sensor will point at the center of illumination and not at the geometrical center of the body (local vertical). Of course in this case, the technique has the added advantage of pointing the cameras at the illuminated portions of the lunar surface from which the best photography could be obtained. (S)

Cameras were started as soon as the lunar sensor had achieved lock-on and continued to run until the film supply was depleted. At this time, the moon sensor was disconnected from the control system and a new attitude reference became necessary.

From an RF transmission standpoint it was probably necessary to re-establish the antenna axis toward the earth. There is no indication in any of the reports that this was done. Since there is also no mention of a sensor capable of acquiring the earth, it seems probable that such an orientation, if accomplished, was done in an open loop fashion. Both the angular orientation and position of the spacecraft were known during camera operation; thus a reorientation toward the earth could be programmed through the rate gyros. After this fairly precise alignment, the spacecraft could be respun about its longitudinal axis to again maintain an inertial alignment. The highly eccentric orbit which resulted after moon passage, however, would not maintain this pointing within the accuracy necessary (approximately 35°) for any lengthy period. The possibility exists of course that the power of the probe-borne transmitter coupled with the sensitivity of the ground receivers made the use of a highly directional antenna unnecessary, particularly as the probe neared the earth after lunar passage. (S)

All reports point out that the spacecraft was respun after photography was complete. The Soviets indicated that this was done for temperature control and to assure proper operation of the solar energy storage system as described previously. (U)

This detailed study was performed on Lunik III because more control functions are identifiable on this probe than on any other. The accuracy requirements for attitude control in this application are very lax, and it is doubtful if the sensors employed had much better accuracy than the minimum required. Probably the most restrictive requirement was the lunar pointing required for photography, and this requirement, 3.5°, is approximately one-twentieth of the achievable accuracy of similar U.S. sensors available in 1960. It is felt, therefore, that Lunik III demonstrated little more than a capability to orient a space probe under low accuracy requirements, and a great amount of ingenuity in, and knowledge of, lunar trajectory design. It is also interesting to note that the success of the attitude control function on this particular space probe was contingent on this trajectory design, and thus it displayed very little versatility (as a complete system) for performance of any other mission or even the Lunik III mission under less optimum conditions. ~~(S)~~

The successful Venus probe of February 1961 provides the next indication of Soviet capability for spacecraft control. Although the publicly announced mission of this probe did not require a variety of control functions as did Lunik III, three significant new applications were used:

a. Injection from a parking orbit.

b. Pointable solar panels.

c. A steerable communications antenna.

All three of these are significant advancements in control and indicate a capability for more refined lunar missions. (S)

Unlike the earlier luniks, the Venus probe was not spin stabilized during the cruise phase. The open Soviet literature indicates that only sun orientation was used during the major portion of flight, and that a communications antenna was earth aligned as the probe neared Venus. This statement is substantiated by the employment of three antennae on the probe: a near earth omnidirectional antenna, a medium range antenna mounted on a solar panel, and a long range parabolic dish. Utilizing this announced reference constraint and the geometrical configuration of the probe, certain conclusions can be drawn about vehicular orientation during the cruise phase. The parabolic dish antenna has limited orientational mobility while the solar panels can be rotated through large angles with respect to the probe. As pointed out by West Wing, an orientation with the longitudinal axis aligned perpendicularly to the ecliptic plane would permit operation of both the solar panel system and the dish antenna within the angular restraints present on the probe.

SECRET

The sensing and mechanization methods for such an orientation are presently unknown and will be the subject of further study. (The use of Canopus as a reference star possibly provided the required orientation.) (S)

The significance of this space probe can be determined, however, without a full understanding of the details of operation. The Soviets have demonstrated the ability to:

a. Achieve free flight space orientation by methods other than spin stabilization. This implies reliable sun sensors, and star trackers with a pointing accuracy of approximately 2°.

b. Design a sensor which provides acquisition of the earth at distances of 70,000,000 km. This capability is indicative of a low sensitivity tracker, something not present on any of the SL-1 launches.

c. Design a control actuation scheme which can provide attitude control for extremely long periods. This cruise mode orientation could possibly be provided by momentum storage. (S)

Although none of these accomplishments are particularly outstanding since they are commonplace in U.S. practice, they do provide indicators of future accomplishments. The ability to orient without the use of spin stabilization is particularly noteworthy since it is currently believed that no accurate midcourse correction maneuver is possible with a spinning vehicle. This ability then permits midcourse corrections which are necessary for any highly refined lunar (or planetary) operation. (S)

SECRET

SECTION V

(U) LUNIK IV

The recent Soviet lunar series (SL-2) provides the most current indication of the status of Soviet spacecraft control. As was noted before, little information is presently available from which to originate any definitive analysis. Also because of the complete failure of the January and February attempts, and the only partial success of Lunik IV, it is very unlikely that open source data will be available in the quantity that has characterized previous Soviet successes. Despite this lack of data in the depth desired, certain conclusions and speculations can be made from the available information. (S)

In attempting to hypothesize the sensing techniques and hardware mechanization used to establish the injection attitude of Lunik IV, there is an inclination to assign the sun as the prime reference. This occurs for several reasons: The sun is prominent and easy to acquire, a requirement exists for solar cell orientation, sensor mechanization is simple and reliable, and the Soviets have shown a preference for its use in applications where another source would provide a better reference (Vostok and Cosmos recovery). All these facts would seem to indicate that some use of the sun is very probable. The disquieting fact in this line of reasoning is an indication that the Venus probe was not in the sunlight prior to, or during, injection from the parking orbit. (S)

To determine if this situation existed for the SL-2 series launches, a determination of the sun's position during each achieved or potential parking orbit was made. (Injection was assumed to occur at the points predicted as optimum for each date.) In each case it was found that the probe was (or would have been) in the sunlight for a minimum of 20 minutes prior to injection. This analysis thus indicates that the use of solar orientation for the injection of Lunik IV cannot be discounted from this standpoint. How this injection orientation was actually sensed cannot be specified at this time because of lack of data. (S)

Soviet open source information published just prior to, and during, the flight of Lunik IV indicated that its intended mission was very probably a soft lunar landing, with a close lunar orbit as another possibility. For either of these sophisticated missions, a midcourse correction is a necessity. As stated before, a meaningful midcourse correction is not possible with a spinning vehicle; therefore, it can be postulated with a high degree of certainty that Lunik IV was not spun for cruise mode stability.

It is also very probable that a directional antenna was utilized on Lunik IV to better enable rapid passing of data from the probe. From these considerations the most likely orientation during free flight to the moon would be very similar to that of the Venus probe: a sun orientation to insure proper operation of solar energy cells and an earth orientation to allow proper positioning of the communications antenna. The simplest mechanization to achieve this dual orientation is as described in the hypothetical flight previously. (S)

Based on open source reports and current Soviet state of the art, it is doubtful that Lunik IV had any capability for on-board navigation. This function was most probably performed by interferometer systems or radio telescopes located on the earth (with possible optical backup), and the positional and velocity information thus derived was fed to a computation center where the transfer orbit was calculated. The necessary corrections for the midcourse maneuver were then passed to the probe in the form of rotational movements and velocity to be gained. The velocity requirement could either be given as a specific period of thrust application or an accelerometer setting to terminate thrust. The accelerometer setting method would provide greater accuracy and is the most likely mechanization. (S)

Nothing can be said with any certainty about the proposed Soviet means for guidance and control of a probe as it nears the lunar surface. U.S. studies have shown, however, that some employment of radar measurement is the only feasible method of achieving the required accuracies in present day technology. Thus it is possible that the Soviets also plan to use radar for sensing and guidance of probes intended for soft lunar landing or near lunar orbits. (S)

The most important conclusion that can be drawn from the SL-2 series is that all is not well with Soviet space probes, and it is very possible that both the failure in February and the failure of Lunik IV to accomplish a more definitive mission can be laid on the doorstep of control. Although the February failure can be considered an unusual event in view of the many space launch successes the Soviets have achieved, Lunik IV is a definite indication that neither the injection nor the midcourse phases can at this time be accomplished with any degree of reliability. It may very well be that Soviet technology in the control field cannot produce the more exotic components required for accurate space missions. The achieved accuracy of Soviet ballistic missiles seemingly precludes this statement, however, it merits serious consideration. This series was undoubtedly a tremendous setback to the planned Soviet lunar exploration pacing and could well have formed a partial basis for the recent statements by Sir Bernard Lovell. (S)

If the failure of Lunik IV was indeed due to control difficulties, it can be expected that an intensive testing program will be initiated to prove a reliable spacecraft orientation system. The majority of this testing will be done in laboratories and experimental facilities, but undoubtedly some will be done operationally both through vertical probes and in-orbit test beds such as the TT Cosmos series. (S)

~~SECRET~~

APPENDIX I

An examination of LMSC ESS SR 31 revealed no information which allowed synthesis of Soviet spacecraft control methods for the SL-2 series. Based on timing of the orbit of Lunik IV, however, the following items could be looked for in the analog traces:

a. Evidences of control actions in Telemetry References* 57 and 58. The presence of control forces during this period would indicate probable active attitude control throughout the parking orbit.

b. Possible indications of control methods during injection thrusting in Telemetry References 60 and 61. The channel identifications as given tend to indicate that the autopilot-velocity meter scheme was used for injection guidance. ~~(S)~~

The postulations made on methods for pre-injection orientation and guidance during injection are possibilities; however, they seem to be less likely possibilities. Unless the SSESS have a capability for providing a radio yaw reference during injection, no reference could exist because of the wide range of injection locations necessary. In fact, from the point of view advanced previously, no yaw guidance is necessary. ~~(S)~~

* As enumerated in SR 31

~~DOWNGRADED AT 12 YEAR INTERVALS; NOT AUTOMATICALLY DECLASSIFIED. DOD DIR 5200.10~~

It is also possible that the inertial reference used for launch into orbit could also be used to attain the injection attitude. The use of this method would, because of gyro drifts during the long coasting phase, add significantly to the velocity requirements for the midcourse correction. Use of the sun, or some other external reference, could reduce the drift error with the attendant reduction of the midcourse maneuver. This latter method is more probable since sensors otherwise required aboard the spacecraft could be used for this function. (~~S~~)

(U) BIBLIOGRAPHY

1. Aleksandrov, S. G., and Federov, R. Ye.: Soviet Satellites and Space Ships, FTD-TT-62-121/1+2, 23 February 1962. (U)

2. Bemet, H. I.: Lunar Guidance, Astronautics, September 1960, pages 24, 25, 77-79. (U)

3. Bodner, V. A., and Seleznev, V. P.: Theory of Three Axis Stable Systems Employing External Information, ARS Journal, May 1962, pages 819-825. (U)

4. Buchheim, R. W.: Lunar Instrument Carrier, Rand RM-1730, 4 June 1956. (U)

5. Cummings, C. I.: The Shape of Tomorrow, Astronautics, July 1960, pages 24, 25, 91. (U)

6. Ergin, E. I. et al: Techniques for Analysis of Nonlinear Attitude Control Systems for Space Vehicles, ASD-TDR-62-208, Volume III, June 1962. (U)

7. Grasshoff, L. H.: Method for Controlling the Attitude of a Spin Stabilized Satellite, ARS Journal, May 1961, pages 646-649. (U)

8. Leliakov, I. P., and Savo, T. A.: Communication Satellite Attitude Control, Aerospace Corporation, August 1962. (U)

9. Pfeiffer, C.: Simple Guidance for Deep-Space Booster Vehicles, JPL TR 32-128, November 1961. (U)

10. Rausenbach, B. V.: Some Guidance Problems in Interplanetary Space, ARS Journal, November 1961, pages 1624-1630. (U)

11. Roberson, R. E., ed: Methods for Control of Satellites and Space Vehicles, WADD TR 60-643, 31 July 1960. (U)

12. Ryabov, B. A.: Navigation and Gyroscopic Devices, FTD-TT-63-473, 7 June 1963. (U)

13. Sedov, L. I.: The Orbits of Cosmic Rockets Towards the Moon, Astronautica Acta, Volume VI, 1960, pages 16-30. (U)

14. Sirri, N.: Space Vehicle Attitude Control, JPL TR 34-121, 2 October 1960. (U)

15. Instrumentation, Guidance and Navigation for Soviet Aerospace Vehicles, Volume II, TIS-EL-61-3, 20 October 1961. (S)

16. Lunar Launch Conditions for the Period 1 May 1963 to 31 December 1963, PWW-TR-63-4, 15 May 1963. (S)

17. Soviet Space Systems, FTD-TS-62-19, 26 April 1963. (S)

18. (C) Soviet Space Vehicle Instrumentation (Lunik III), U.S. Army Signal Intelligence Agency, ST-175.1-60, June 1960. (C)

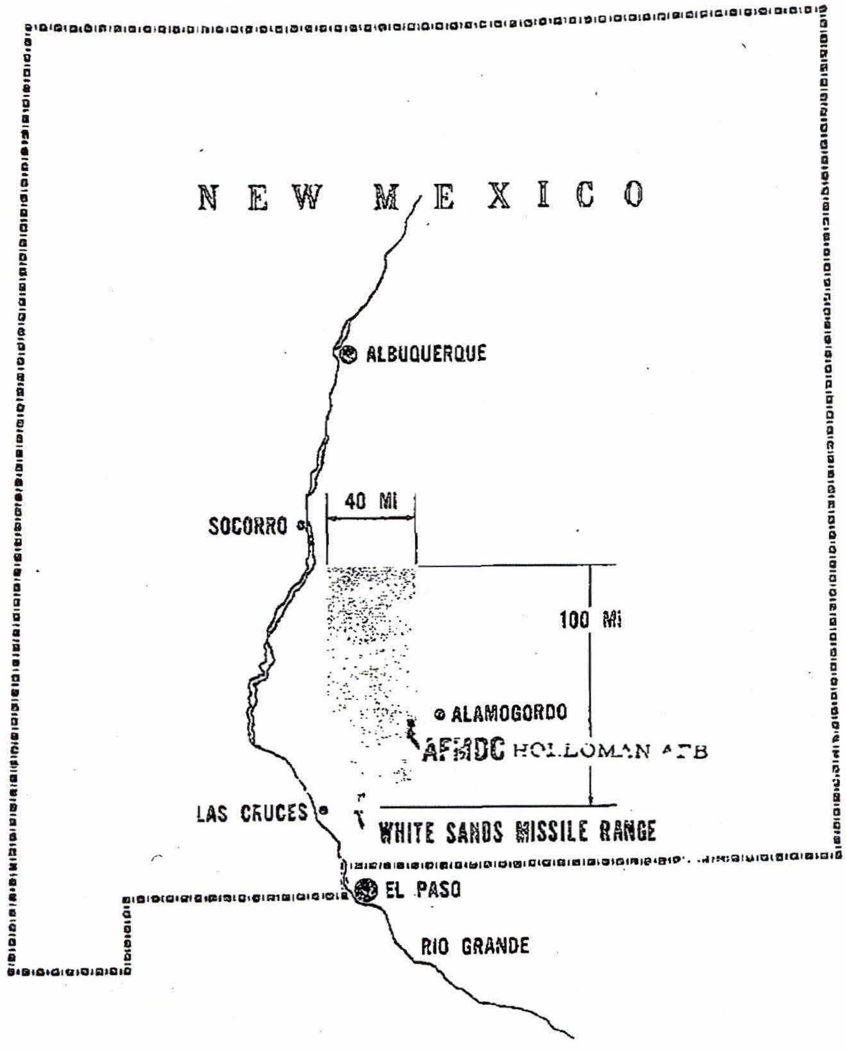
19. The Lunar Program, Space Program Summary Nr 37-21, Volume I, JPL, 31 May 1963. (C)

20. Electronic Signal Studies Preliminary Flight Report, PFR-Z533, LMSC, 29 March 1963. (S)

21. Electronic Signal Studies Working Paper, ESS WP-122, LMSC, 9 August 1963. (S)

DISTRIBUTION

Organization	OPR	Copy Nr
FTD	TDES	01-02
FTD	TDFS	03-04
FTD	TDBDP	05-09
AFSC	SCFD	10-11
BSD	BSF	12-13
SSD	SSF	14-15
ASD	ASF	15-17
ESD	ESY	18-19
AMD	AMF	20-21
RADC	RAY	22-23
AFWL	WLF	24-25
AFFTC	FTY	26-27
AFMTC	MTW	28-29
APGC	PGF	30-31
AEDC	AEY	32-33
RTD	RTGS	34-35
AFMDC	MDO	36
AFMDC	MDNH	37



AREA MAP SHOWING LOCATION OF AFMDC