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(U) VOSTOK CONTROL EQUIPMENT

DECEMBER 1963

TASK 618204(3.3.9.1)

AIR FORCE MISSILE DEVELOPMENT CENTER

DEPUTY FOR FOREIGN TECHNOLOGY

AIR FORCE SYSTEMS COMMAND

HOLLOMAN AIR FORCE BASE

NEW MEXICO

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AFMDC-TR 63-[illegible]

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VOSTOK CONTROL EQUIPMENT

December 1963

Task 618204(3.3.9.1)

Prepared by:

Captain James E. Howard

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DEPUTY FOR FOREIGN TECHNOLOGY
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PREFACE

The information reflected in this report has been prepared primarily for the use of Foreign Technology personnel engaged in the analysis of the Soviet space effort. The study of the Soviet space effort is an Air Force Systems Command project, and this report will be of particular interest to individuals concerned with Soviet spacecraft control equipment. This is a technical support document for Project 6182, Task 618204(3.3.9.1), assigned to the Air Force Missile Development Center.

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

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Lt Col, USAF
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AFMDC 63-6229

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(U) SUMMARY

Purpose

This report presents the results of analysis initiated to satisfy Task 618204(3.3.9.1) of the Vostok TOPS. (U)

Conclusions

a. In-orbit orientation of the Vostok is accomplished through the use of horizon scanners in pitch and roll, and a yaw gyro in yaw.

b. Control torques during this period are provided by a cold gas storage system.

c. High level torques during periods of rapid reorientation are provided by a hot gas system (possibly H_2O_2).

d. The solar orientation system for deorbit consists of a solar sensor and rate gyros. The sun provides an orientation checkpoint for establishing an inertial reference through these gyros. This system provides the necessary elements for control of the vehicle during all periods other than in-orbit. (S)

Background Highlights

This report was prepared from extensive Soviet open source literature and various studies on Vostok attitude control. Neither telemetry nor definitive telemetry studies were available for this analysis. (S)

The system postulated in this report is slightly unusual in the sense that a solar reference is used to establish an orientation with respect to the earth. From the Soviet descriptions of the system and its operation, it is very probable that this method is necessary because the sensors used for in-orbit control do not provide adequate accuracy for deorbit and re-entry orientation. (S)

Discussion

Because of the many existing gaps in the information available for analysis of the Vostok control system, certain assumptions are necessary to allow complete component specification. To make these assumptions valid, the control requirements for a recoverable manned satellite must be firmly established, the Soviet penchant for reliability and simplicity must be accounted for, and the early (1958-60) design period must be recognized. Although none of these factors can actually pinpoint design, they do provide analysis constraints which limit selection to the most probable components from the myriad of possibilities. (S)

The initial step in this analysis was a review of all the existing studies on various aspects of Vostok attitude control. It was immediately apparent that little agreement existed among the many agencies which had postulated control systems. One system synthesized was completely unrealizable by either 1959 or 1963 control technology; at least two others were so restricted in operational flexibility as to be extremely unlikely. ~~(S)~~

In an attempt to bypass these pitfalls, a review of U.S. control technology in the time period of Vostok design was made. Reference 5 provided the majority of information for this review both from a theoretical and a practical standpoint. (U)

From this base a minimum system was established which met all the Vostok control requirements for the missions as flown. Since this was a minimum system, it was the simplest and most reliable one which could be established from U.S. design technology in the applicable time period. The system thus established was then modified to fit Soviet open source descriptions, the available covert data indicating design, and the Soviet control system capabilities previously demonstrated. ~~(S)~~

An examination of the Vostok test program indicates that perhaps a change was made in the deorbit orientation system during this test phase. In the detailed Soviet descriptions of both Sputnik 4 and Sputnik 5, no mention is made of any "solar orientation system" for other than control of solar panels. This is considered significant because such a system was extensively described as being an integral portion of the control system of Vostoks 1 and 2. If a change was made, it came after the second deorbit failure, Sputnik 6, In view of the short time period between this failure and the successes of Sputniks 9 and 10, a new system probably could not have been developed. The Soviets would thus be forced to modify a proved system to fit this application. The only applicable system which existed at that time, and which had also successfully performed in space, was the solar sensor-gyro orientation system used on Lunik III. Interestingly enough, the Soviet descriptions of the two systems are very similar. In each case, both solar and gyroscopic sensors are described as integral elements. (S)

The control system which results from following the procedures and thinking outlined above is reasonable and realizable, at least by U.S. standards. Further, it is flexible enough to meet orientation requirements under a variety of circumstances, and is also a logical extension of previous Soviet accomplishments in attitude control. ~~(S)~~

SECTION I

(U) AUTOMATIC IN-ORBIT CONTROL SYSTEM

The functional requirements of any space vehicle are determined largely by the trajectories and regions of space through which the vehicle passes in realizing its operational concept. Theoretically a manned orbital vehicle need have no more control than that necessary for deorbit and re-entry. As a practical matter, however, the vehicle is controlled in orbit to allow ground surveillance and the initiation of any required maneuvers. This flexibility requires a reference system establishing a vertical relative to earth and a forward direction in the orbit. The speculation that this is, in fact, the orbital reference used in the Vostok vehicles is substantiated by Reference 1:

"The longitudinal axis of Vostok II was directed almost tangentially toward the trajectory of their centers of gravity. Such orientation was convenient in that the ship could more precisely transition to a previously computed trajectory for a landing on earth. . . . When there is orientation with relation to the earth, the axis of the ship must form a definite angle to the vertical (for example, a right angle)." (U)

Reference 2 was even more specific in its description of the orientation of Sputnik 5:

"During operation of the orientation system, one axis of the ship was directed along the local vertical and the other one perpendicular to the orbit plane; the third (longitudinal axis) perpendicular to the first two, along the intersection of the plane of the local horizontal and the orbit plane." (U)

These two descriptions are compatible since an axis perpendicular to the local vertical will be tangent to the trajectory only in a circular orbit. For eccentric orbits, such as those of the Vostoks, this longitudinal axis will be almost tangent. ~~(S)~~

Having established the nominal orbital attitude, it is now possible to determine the most probable sensor mechanization used to achieve this orientation. Although there exist several local verticals which can be sensed for attitude control, the simplest and most accurate (by 1958-60 U.S. state of the art) scheme uses horizon scanners to establish both the pitch and roll axis attitude by sensing the geographic horizon. The concept of horizon tracking can be mechanized in many ways; essentially each scheme examines a localized segment of the earth's periphery and develops a usable output signal at the line of maximum intensity gradient. This maximum gradient generally occurs at the earth-space interface, and the output signal is thus proportional to the angle between the sensor axis and the horizon. This information, properly processed, results in orientation of the vehicle with respect to the horizon. Use of a scanner in pitch and one in roll (or one which scans the entire horizon) provides stabilizing signals for each axis, thus establishing the local vertical. (S)

The Soviet mechanization of this concept cannot be determined from available data; in fact, it is only a postulation that horizon scanners are used at all. In all the Soviet open literature screened, a horizon scanner or sensor has never been identified as an included component on any spacecraft except for a casual mention in the September 1961 issue of USSR in which it was noted that the attitude reference of Vostok II was determined by "scanners." This interesting fact has possible implications which will be discussed in a later report. (S)

Despite the lack of knowledge of the exact mechanization used by the Soviets, certain conclusions about the horizon scanners can be reached because of the characteristics common to this class of sensors. They operate in the IR spectrum (1 to 30 microns) to permit orientation on the night side of earth, a mechanical motion is required to accomplish scanning, random errors are introduced by the geometry of the horizon and atmospheric physics, and accurate operation is generally limited to small angular excursions about nominal. Achievable accuracies, under worst operating conditions, of U.S. horizon scanners vary from approximately 0.5° to 1.0°. This capability is adequate for manned satellite orbital orientation and also for deorbit orientation of nonlifting blunt body re-entry vehicles which do not require pinpointing of impact locations. (S)

In accordance with the component simplicity constraint, it is postulated that a yaw gyro is used to provide the necessary reference for the remaining stability axis. This mechanization can be accomplished using the gyrocompass principle or by a rate gyro which indicates a component of the orbital rate when yaw is off nominal. As before the exact scheme employed by the Soviets cannot be specified; the gyrocompass utilization is more likely because of the time period of development. (S)

In the simplest mechanization, each stability axis is controlled by an independent control loop. Both the pitch and roll axis loops require a computer to derive the error signal; all three loops contain an amplifier which can also serve to generate the necessary stability derivatives of the error signal. It is also possible that a general computer may be included among the on-board components to perform necessary re-entry computations.

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SECTION II

(U) MANUAL CONTROL SYSTEM

The manual control system employed on the Vostoks is described in Reference 3. No significant differences in physical or operational characteristics from those presented in that report were discovered during the course of this analysis. ~~(S)~~

SECTION III

(U) CONTROL FORCE GENERATION

The torque generation system used on these vehicles is mentioned and described many times in the open literature. It is a mass expulsion system using a cold (pressurized) gas. It is likely that there are actually two separate systems -- one for automatic control, and one for manual control. The manual system would necessarily utilize a separate gas supply to increase reliability through redundancy. This separation of the systems is substantiated by descriptions which place a portion of the orientation system (automatic) in the nonrecoverable instrument section and the remainder (manual) in the recoverable cabin. (S)

One of the basic limitations of a cold gas system is the low thrust level available; typically 0.2 to 0.3 pounds. These levels make reorientation of a vehicle of the mass of a Vostok a slow process. A rough calculation using the estimated Vostok configuration indicates a 10- to 15-minute period is required for a 180° turn, as is apparently required for re-entry. Although according to Soviet claims submitted to the FAI, a period of this length is available from initiation of orientation to deorbit, a comparison of times of entry into sunlight (which is indicated in all Soviet reports as the initiation of orientation) with the probable times of retrofire indicates a marginal available time period. Also safety precautions at injection into orbit probably require the capsule be in the deorbit attitude for the first several minutes of the zero orbit. Since this maneuver must occur immediately upon injection, the time required for cold gas reorientation is not available. For these reasons it is highly probable that a hot gas system (possibly H_2O_2) is also employed on the Vostok for those periods when rapid reorientation is required. ~~(S)~~

The postulation of this high thrust level system answers another question about Vostok control -- namely, control force generation during the re-entry period after the instrument compartment containing the automatic system has been jettisoned. This system, as an integral component of the cabin, would provide the necessary control forces to stabilize the re-entry vehicle during passage through the atmosphere and during that period from separation of the instrument section until re-entry of the cabin began. ~~(S)~~

SECTION IV

(U) DEORBIT AND RE-ENTRY CONTROL

The system so far synthesized is capable, at least theoretically, of providing the necessary control for a recoverable satellite. Soviet releases, however, indicate that such is not the case. The deorbit orientation process is described by Reference 2:

"Prior to descending into a given region, the ship satellite, prior to retrothrust, must acquire perfectly definite orientation in space. This problem is solved by the orientation system. In the given flight (Vostok I) orientation is realized by orienting one of the ship's axes in the direction of the sun. The sensitive elements of that system are a number of optical and gyroscopic sensing elements. The signals entering these elements are converted in an electron block into commands regulating a system of control organs. The orientation system provides automatic scanning of the sun, proper turn of the ship, and keeping it in the required position with greater accuracy." (S)

Reference 4 provides an indication of the importance of the sun to deorbit:

"In case of failure of systems providing automatic descent, or upon the necessity of making an emergency descent when the orientation on the sun is not possible, he switches on the system of manual control... and having made an accurate orientation, begins deceleration." (U)

Similar descriptions have appeared in many Soviet reports of Vostok operations. These statements can be (and have been) interpreted in many ways, but the one undisputable fact is that a separate orientation system which requires the sun as a reference is used to establish the deorbit attitude. The significance of this fact is relatively unimportant in considerations of manned vehicle recovery; it simply means that the launch time must be controlled to insure proper sunlight conditions for programmed deorbit (as is done). The implications are extremely important to other applications of deorbit techniques, however. As noted before, the horizon scanner-yaw gyro system should provide adequate accuracy for deorbit and re-entry; but, by Soviet admission, it does not meet some criteria and is replaced at the most critical portion of the mission. If it is assumed that this switch is made because of accuracy limitations (as is done here*), the logical conclusion is that the Soviets cannot, with Vostok control technology, employ a

*The argument that the solar orientation system is added because of increased sensor reliability seems illogical upon examination of the description of Reference 4.

system which can be deorbited except at certain rigidly fixed times. In other words, a flexible orbital bomber is not technically feasible using the Vostok deorbit system. This subject will be discussed in detail in a future report. ~~(S)~~

The actual deorbit attitude of the Vostoks has been the subject of much speculation and analysis. All of these studies have shown that a reasonable re-entry trajectory can result from a variety of deorbit orientations, including a direct pointing at the sun during the application of retrothrust. It is not the purpose of this study to add to this controversy, but rather to attempt to explain the quoted statements above in terms of reasonable control applications. Of necessity, however, certain other mission considerations must be included in the discussion. ~~(S)~~

For successful deorbit and re-entry the control system is essentially required to:

a. Establish and maintain the required orientation for retrothrust.

b. Provide thrust vector control of the retro impulse.

c. Reorient the vehicle to the proper re-entry attitude.

d. Insure stability of the vehicle during atmospheric penetration. (U)

In the Vostok case, orientation for retro apparently begins as the vehicle enters sunlight on the final orbit. The sun seekers then turn the spacecraft to "point one of the ship's axes at the sun." There are several indications that a 180° turn in yaw is made during this initial solar acquisition. Although the axis which is pointed at the sun is not identified, the longitudinal axis is the logical choice because the most critical attitudes, pitch and yaw, can be established directly. Orientation in roll during this sun pointing period would most simply be furnished by the roll horizon scanner. Sun pointing of any other body axis, or an arbitrary axis, would result in degradation of orientation accuracy in either pitch or yaw, and would increase the on-board computation required to establish the deorbit attitude. ~~(S)~~

The disadvantage in using solar orientation to establish the deorbit attitude results from the increased maneuvering required, with the attendant increase in control fuel requirements. The advantage is orientation accuracy. The sun furnishes an orientation checkpoint which establishes the pitch and yaw attitudes to a greater accuracy than possible with the horizon scanner and yaw gyro. ~~(S)~~

It is well documented that sun pointing takes place during the initial portion of the deorbit orientation; subsequent maneuvers requirement causes it to operate in an unnatural mode. The control system sees this moving reference as a high level, continuously varying (in yaw) disturbing torque. Although the exact extent of this effect cannot be determined without a detailed knowledge of both the vehicle configuration and the control logic used, such a disturbance will result in a degradation of accuracy, a large increase in control fuel consumption, and continuous hunting for the desired attitude. In fact the large increases in the sun's azimuth which begin to occur just prior to retro could drive the yaw loop out of limit cycling, making this attitude highly inaccurate at the most critical point. Thus, through the constant solar orientation requirement, the inherent accuracy of a solar sensor is severely degraded, defeating the reason for its employment in the first place. ~~(S)~~

Discounting the sun pointing deorbit scheme, an alternative must be postulated which satisfies the characteristics disclosed by the Soviets, and which insures better accuracy than the horizon seeker-yaw gyro reference used in orbit. ~~(S)~~

The basic limitation of gyros in space applications is their inability to maintain an accurate long term reference because of drift. To overcome this limitation, a great deal of work is being done both in this country and in the USSR on stellar-inertial systems. In these systems the gyro reference is periodically updated by stellar information, thus eliminating the drift errors. Although a system which could perform for prolonged periods in space is at present beyond the state of the art for anyone, this technique can be applied to earth satellites. In the Vostok orientation for deorbit and re-entry, this technique is, with a high probability, the scheme employed. In this case the sun furnishes the stellar reference necessary for accurately establishing an inertial attitude for subsequent maneuvers. (S)

It is postulated that this solar orientation checkpoint provides the necessary reference through rate gyros for all subsequent control requirements. The operation of the system is as follows:

a. As the vehicle comes into the sun on the recovery orbit, the "solar orientation system" begins its operation. The longitudinal axis is aligned to point directly at the sun establishing an accurate orientation in yaw and pitch. As before, the roll horizon scanner establishes the roll orientation. Once this attitude is established, body-mounted rate gyros are uncaged and an inertial attitude reference is established. Subsequent maneuvers to the desired deorbit attitude are made through precalculated and stored torquing commands to these gyros.

Once this gyro reference is established, the solar sensor is no longer necessary and can be electronically removed from the control system. (S)

b. These gyros, with the capability for two modes of operation, provide the required inputs for control of the remainder of the flight. In the first mode, gyro torquing devices are utilized to command the necessary turns for reorientation of the vehicle for deorbit and re-entry. The required stability inputs of position during this period are derived by integration of the rate proportional torquer currents. In the second mode (used for retro and re-entry), the gyros act as rate sensors. During retro the required error signals are developed from these rate outputs and the thrust vector control actuator positional information. During re-entry simple rate damping would provide the necessary stability. These same gyros also provide the control system inputs to orientation at injection. The necessary inertial reference would be established during injection stage burning from the injection stage reference; mode 2 operation would stop the arbitrary rotation resulting from separation of the stage, and mode 1 operation would orient the vehicle for possible emergency deorbit during the early minutes of the zero orbit. (S)

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SECTION V

(U) GUIDANCE AND NAVIGATION EQUIPMENT

Precise position determination and ephemeris data for the Vostoks were computed at ground stations from tracking data. The only on-board navigation performed was through the "Globus" device, and this was of a predictive nature. That is, the future position of the vehicle was determined on the ground and was made available as a cockpit presentation through proper rotation of the globe mounted on the instrument panel. (S)

No guidance function, in the usual sense, was performed on board the vehicle. Although there were accelerometers noted in the spacecraft telemetry, they apparently were used for environmental data, and not for regulation of the velocity decrement at retro. (S)

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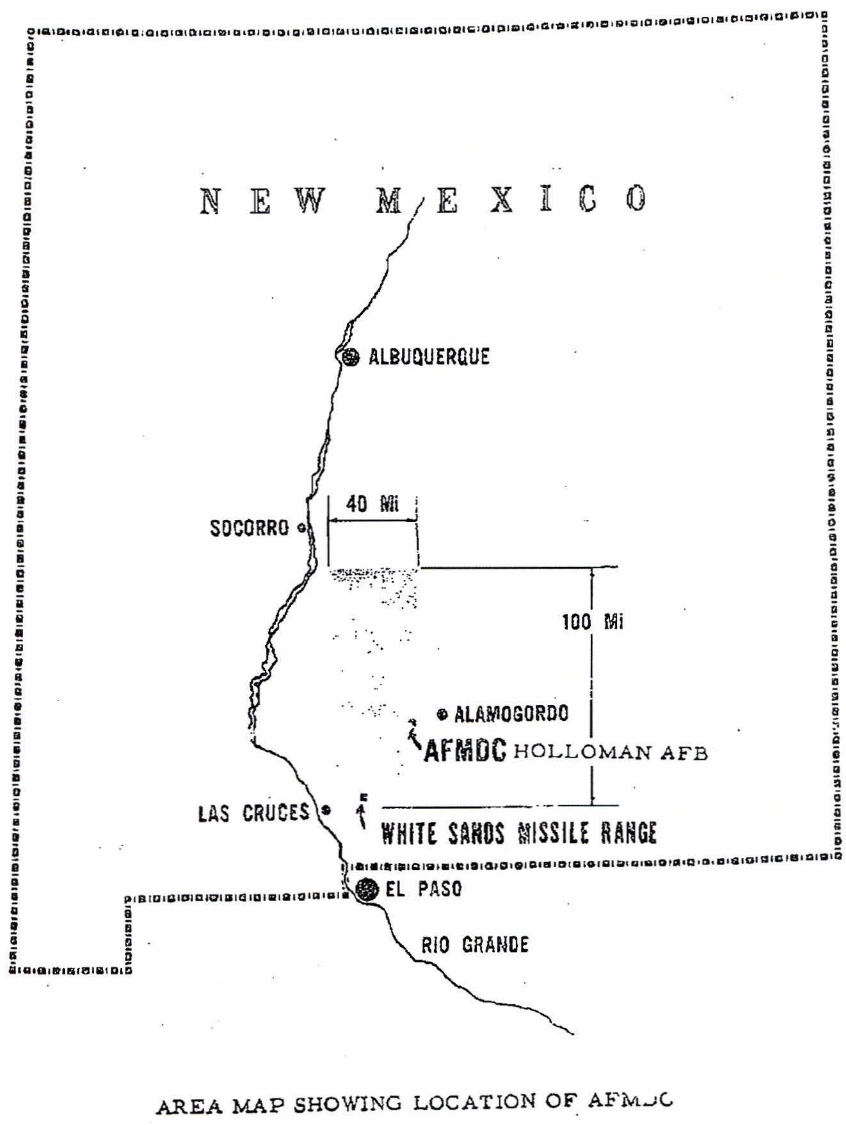

AREA MAP SHOWING LOCATION OF AFMDC