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Technical Report

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(U) PLANETARY EXPLORATION SYSTEM (PES) LAUNCH VEHICLE GUIDANCE AND CONTROL SUBSYSTEMS

NOVEMBER 1963

TASK 6182(44)

AIR FORCE MISSILE DEVELOPMENT CENTER

DEPUTY FOR FOREIGN TECHNOLOGY

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AIR FORCE SYSTEMS COMMAND

HOLLOMAN AIR FORCE BASE

NEW MEXICO

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FOREIGN TECHNOLOGY REPORT

AFMDC-TR-63-4

(Title Unclassified)

PLANETARY EXPLORATION SYSTEM (PES) LAUNCH VEHICLE GUIDANCE AND CONTROL SUBSYSTEMS

November 1963

Task 6182(44)

Prepared by:

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HOLLOMAN AIR FORCE BASE, NEW MEXICO

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(U) PREFACE

The information reflected in this document has been prepared for the use of Foreign Technology personnel engaged in the analysis of the Soviet space effort. This is an AFSC project, and this contribution will be of particular interest to analysts concerned with Soviet space probe guidance systems and components. This report serves as a technical support document for Task 6182(44) assigned to the Air Force Missile Development Center. (S)

(U) PUBLICATION REVIEW

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

FOR THE COMMANDER

Howard L Conkey

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

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(U) SUMMARY

Purpose

This Technical Report was prepared to meet requirements established on page 56 of the Foreign Technology Division Soviet Planetary Exploration Program TOPS. It fulfills Task 6182(44) of the referenced TOPS. ~~(S)~~

Conclusions

a. The boost stage and the sustainer stage of the planetary launch vehicle use a radio-inertial guidance system. The vehicle is controlled in yaw by radio. The pitch plane guidance is probably inertial. ~~(S)~~

b. The third stage which kicks the heavy earth satellite into earth orbit is believed to be all inertial. ~~(S)~~

c. During the coast phase (while the satellite is orbiting the earth), the satellite is tracked accurately by earth stations to obtain ephemeris data. This data is transmitted to a central computation center. The corrections required in the fourth stage guidance program as a result of the deviation of the satellite from a nominal orbit are computed at the computation center. ~~(S)~~

d. The required corrections to the fourth stage program are transmitted to the vehicle either directly from an earth station or via Soviet ships at sea. ~~(S)~~

e. At the computed time, the planetary probe is ejected into a planetary trajectory at a precomputed angle. The magnitude of the impulse is determined by either a timer which shuts down a constant thrust engine after a predetermined time or by an integrating accelerometer which shuts off the engine when the velocity-to-be-gained equals zero. ~~(S)~~

f. The accuracy with which the fourth stage is injected into planetary trajectory is estimated to be approximately as follows:

launch time	1.4 minutes
velocity	3.0 meters/sec
direction	10.0 minutes of arc ~~(S)~~

Background Highlights

From 10 October 1960 to 4 November 1962, at least ten Soviet vehicles were detected which are believed to have been attempted Mars probes or Venus probes (see Table I). Of these, only two - the Venus probe of 12 February 1961 and the Mars probe of 1 November 1962 - are classed as successes in that they were successfully injected into planetary orbits. Both of the successes as well as the eight failures are believed to have utilized a parking orbit. ~~(S)~~

It is believed that identical launch vehicles have been used for the probes. The system has been designated as the SL-1 system.

TABLE I

(U) SOVIET MARS AND VENUS PROBES

Date	Mission	Sputnik Nr	Z-Number	Comments
10 Oct 60	Mars		Z280	Unsuccessful
14 Oct 60	Mars		Z281	Unsuccessful
4 Feb 61	Venus		Z309	Unsuccessful
12 Feb 61	Venus	Sputnik VIII	Z[illegible]	Success via parking orbit
25 Aug 62	Venus	Sputnik XXIII	Z533	Unsuccessful
1 Sep 62	Venus	Sputnik XXIV	Z534	Unsuccessful
12 Sep 62	Venus	Sputnik XXV	Z535	Unsuccessful
24 Oct 62	Mars	Sputnik XXIX	Z575	Unsuccessful
1 Nov 62	Mars-1	Sputnik XXX	Z585	Success via parking orbit
4 Nov 62	Mars	Sputnik XXXI	Z595	Unsuccessful

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It is believed to consist of the booster and the sustainer of the SS-6 missile, plus a third stage known as the Venik rocket which first appeared on the 10 October 1960 attempt and a fourth stage which is believed to be the Lunik upper stage. ~~(S)~~

Discussion

It is generally agreed in the intelligence community that the first two stages of the launch vehicle for the Soviet space probes are the booster and the sustainer of the ICBM-A. The ICBM-A is believed to be guided with a radio-inertial system. Speculations on the specific details of the radio-inertial system are not abundant in the literature; neither are the existing speculations all in agreement. ~~(S)~~

Though it is generally agreed that the radio portion controls motion in the yaw plane, the type of radio guidance involved is more speculative and more diverse in the final conclusions. Some reports describe the system as a radar track and command system consisting of four radar sets located at the ends of the arms of a cross. A computer receives data from the radar sets, computes the necessary corrections to the trajectory, and then transmits command signals to the vehicle via the radar sets. (8, 11 12, 19)*

*All parenthetical superscripts reflected in this report are references listed in the Bibliography.

Others [6] estimate the yaw guidance to be a LORAN type system in which the time of arrival of signals from two transmitting antennas is measured by the vehicle. The guidance commands are then derived from these times. The author prefers the LORAN concept since it offers the required accuracy while the equipment requirements are much less than the radar concept. The LORAN concept is a direct follow-on to the yaw plane guidance system used by the Germans on the V-2. ~~(S)~~

Although reliable data is practically nonexistent on the guidance for the third and fourth stages, most analysts seem to believe that these stages are also radio guided. The author believes the third and fourth stages to be inertially guided according to a precalculated program. Precise tracking of the heavy earth satellite after injection into orbit decreases the accuracy requirements for third stage guidance. Errors in the injection parameters can be calculated from the tracking data and then compensated for by changing the program in the fourth stage. Similarly, the midcourse correction can compensate for errors in fourth stage parameters. In general it is believed an autopilot grade inertial system would be adequate. ~~(S)~~

The remote areas over which the third and fourth stages are sometimes initiated also argue against ground radio command guidance. The third stage might be ignited downrange 1,600 nm from the launch point. The fourth stage for the Venus probe was ignited over North Africa and shut down over Northern Turkey. If the vehicle is launched in other than a 65° orbit (as Lunik III was), the third stage ignition will occur at some point which does not lie along the trajectory normally utilized by vehicles launched by Tyura Tam. Consequently, the third stage might not be able to utilize effectively the standard range instrumentation. An all-inertial system eliminates the dependence on ground instrumentation. (~~S~~)

SECTION I

(U) BOOSTER AND SUSTAINER GUIDANCE

It is estimated that the booster and the sustainer stages utilize the SS-6 radio-inertial guidance system. The system consists of inertial components to control motion in the pitch plane and a radio system for yaw plane guidance. ~~(S)~~

Two free gyros are used in the inertial system. The gyros have no internal damping and might use potentiometer pickoffs. One gyro, oriented with its spin axis parallel to the pitch axis, controls both roll and yaw. The second gyro controls pitch. Its spin axis is parallel to the yaw axis. It is preprogrammed to assure missile flight along the desired powered flight trajectory (see Fig. 1). The estimated gyro parameters are given in Table II. [5] The outer gimbal of both gyros are pivoted about the roll axis. The relative low resolution of the gyro pickoffs, approximately 8 minutes of arc, indicates that the gyros are used primarily for stability and control. Integrators in the forward loop of the control system reduce steady state errors to assure flight along a predetermined trajectory. [5] ~~(S)~~

The radio system for the yaw plane guidance is of the LORAN type. An on-board receiver measures the time of

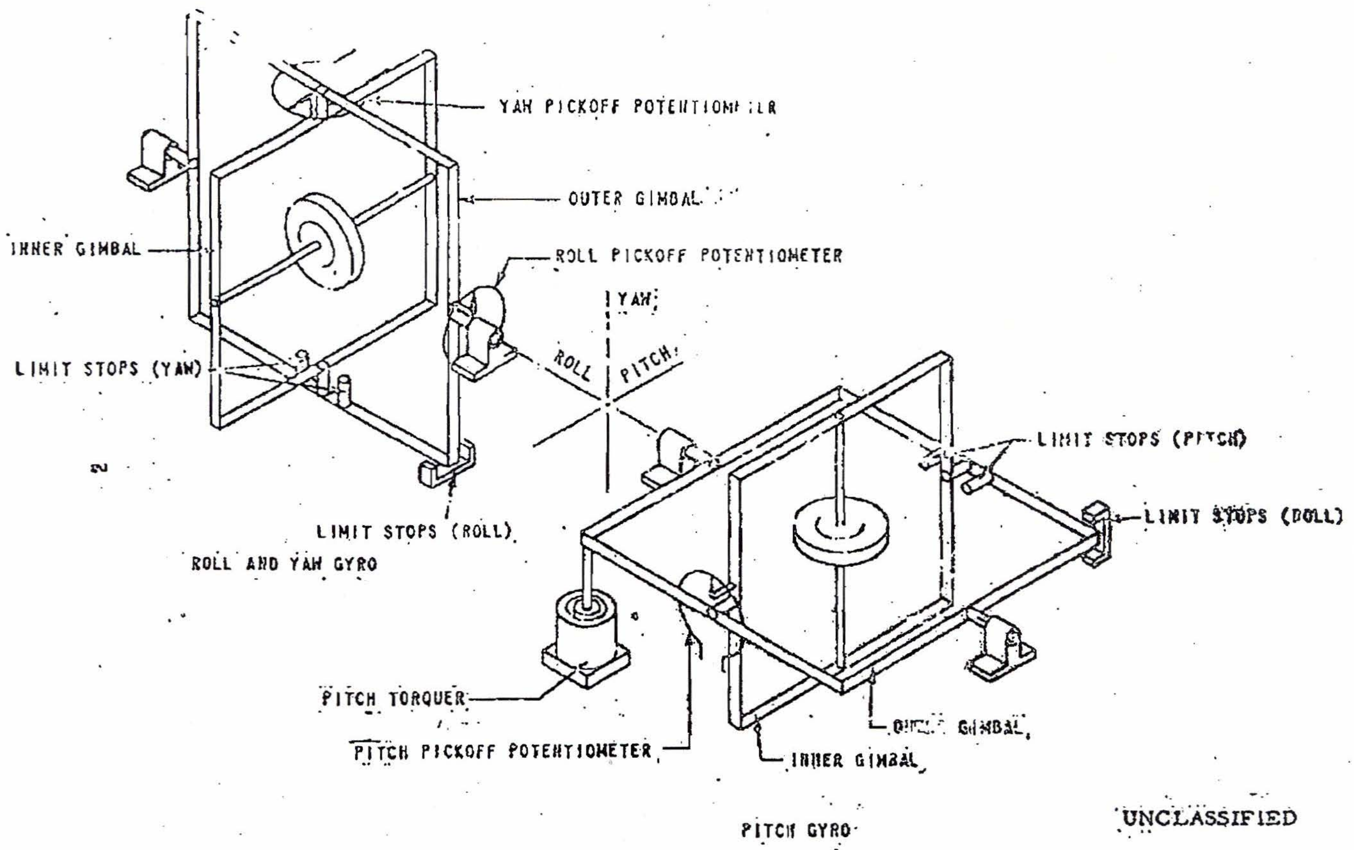

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Fig. 1 Hypothetical Orientation of Autopilot Gyros

TABLE II

(U) AUTOPILOT GYRO PARAMETERS

Specifications for this autopilot are as follows:

Type of gyros	Two-degree of freedom
Number	Two

Calibration and Resolution Factors

Channel Nr	Cal Factor	Resolution
1	15 degrees/100% cal	8.5 minutes of arc
2	15 degrees/100% cal	8.5 minutes of arc
3	20 degrees/100% cal	8.5 minutes of arc

Gyro Precession Rates (Maximum)

Inner Gimbal	~800 degrees/second
Outer Gimbal	~600 degrees/second
Type of Damping	None
Pitch Torque	Inductive device attached to the outer gimbal of Gyro A
Pickoff Device	Fairly low impedence wirewound potentiometers
Gyro Gimbal Bearings	Probably ball bearings; the gyros are not floated and there is no evidence of air bearings
Rotor Moment of Inertia	Unknown, but probably not more than $10X10^5$ --cgs units
Autopilot Function	Flight stability and possibly rough aiming

arrival of a signal from two transmitting stations. The missile is steered so that a desired and predetermined condition regarding the signal time of arrival is maintained. ~~(S)~~

Integrating accelerometer(s) on the missile measures the velocity and the position of the vehicle as a function of time. The measured values are compared with precalculated, preprogrammed values to generate error signals. The error signals thus generated control thrust magnitude and thrust direction to assure that the programmed values for velocity and position are followed. When some predetermined condition of velocity and position is attained, the engine is shut down. Alternately the engine can be shut down strictly at a predetermined time, since if the velocity and position program is followed, cutoff will always occur after a well-defined time interval. ~~(S)~~

SECTION II

(U) THIRD AND FOURTH STAGES GUIDANCE

The fourth stage of the launch vehicle contains the guidance equipment for both the third and the fourth stages. The guidance is estimated to be an all-inertial system. The system consists basically of body-mounted gyros for attitude control and an integrating accelerometer or a timer for thrust termination. With a good tracking system, minor errors in the satellite orbit parameters are tolerable since these errors can be compensated for in the fourth stage by correcting the firing angle, firing time, and the magnitude of the fourth stage impulse. (~~S~~)

Fluctuations in the inclination angle for injection into earth orbit (assuming that the same inclination angle was the goal each time) vary about 0.1 degree around the mean from one orbit to the next. Similar observations for other Soviet LOV (Sputniks and Cosmos vehicles) which are also believed to use the booster and sustainer of the SS-6 show that the burnout velocity is controlled to an accuracy of about ± 50 ft/sec and the burnout angle to within about 6 minutes of arc. Consequently, the satellite injection guidance errors for the space probes are believed to be the same - i.e., ± 50 ft/sec in velocity and burnout angle error of ± 6 minutes of arc. (~~S~~)

SECTION III

(U) ORBITAL COAST PHASE

The third stage of the launch vehicle places a heavy satellite into earth orbit. The heavy satellite contains the space probe. The actual orbit attained will differ from the nominal orbit calculated prior to the launch of the vehicle. This deviation from the nominal is due to launch guidance errors (see Discussion on page vi, and Section II). (The preprogrammed inertial components in the fourth stage have been programmed assuming injection of the satellite into nominal orbit.) ~~(S)~~

The earth satellite is tracked as it passes over the Soviet Union. The data obtained is transmitted to a central computation center where the actual parameters of the earth orbit are calculated and compared with the nominal values. The changes in the fourth stage guidance which are required to compensate for the orbit deviation from nominal are transmitted to the vehicle (possibly via the tracking ships at sea). ~~(S)~~

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SECTION IV

(U) INJECTION INTO PLANETARY TRAJECTORY

The earth satellite carrying the space probe is probably oriented in the direction required for injection of the probe into planetary orbit immediately after third stage burnout. This orientation is maintained throughout the orbital coast phase. ~~(S)~~

"At the time for the launching from the satellite, the possibility arises for the adjustment of these errors which have accumulated during the flight of the rocket carrier from the earth to the orbit of the satellite. (U)

"Improved parameters of movement for the launching base (i.e., the Cosmic rocket carrier for the interplanetary station), can be applied during the introduction of the station into the interplanetary course."[15] (U)

Thus the tracking data obtained from the satellite is used to calculate the impulse required - both in magnitude and in direction - to inject the planetary probe into the proper trajectory. The time at which this impulse must be applied is also determined accurately. Thus the errors accumulated during launch are compensated for by adjusting the parameters of the final thrust which affect the interplanetary burnout conditions. For the one-orbit probes, the calculated corrections are probably transmitted to the tracking ships at sea which in turn transmit them to the orbiting satellite. The corrections required would be firing time, duration of thrust or velocity to be gained, and the flight path angle. ~~(S)~~

The fourth stage guidance is believed also to be inertial. This is substantiated by the open literature in which "programming equipment" is said to be aboard the Venus probe. It is also stated that assisted inertial system is employed. (16) ~~(S)~~

The firing of the fourth stage is probably commanded from earth stations. (The open literature states that the Venus stage was launched from orbital stage by "telemetry control.") (16) Again in Science and Life (Selected Articles), FTD-TT-62-200, it is stated that, "At exactly the right moment, in answer to the command, a fresh rocket carrying inside, it an AMS inter-planetary space ship was launched from the satellite in a strictly determined direction [Venus probe of 12 February 1961]." Depending upon the point of injection, the command can be initiated by either the ships at sea or by stations within the USSR. ~~(S)~~

An estimate of injection errors can be obtained from Soviet statements which have appeared in the open literature:

"To secure the passing of the AIS in the immediate vicinity of the planet, the lifting of the AIS into trajectory must be realized with greater accuracy. Errors in the velocity magnitude by 1-3 meters/sec and errors in heading of velocity of 0.1-0.3° result in change in minimum distance between AIS and Venus by 100,000 km. Such a deviation magnitude is also produced by a 1-minute error in the time of rocket starting." (13) (U)

An article by N. Varvarov (15) states that a 1-minute deviation in launch time will cause a Mars miss of 135,000 km. An error in injection velocity of 30 cm/sec or an error in direction of 1 minute of arc will cause a miss of 20,000 km. "Measurement of the course of the 'Mars I' flight indicates that even this Cosmic ambassador will pass by near Mars at a distance of 193,000 km without consideration of corrections to its trajectory." From these statements made by Varvarov, one can establish the maximum injection errors to be:

launch time	1.4 minutes	
velocity	3.0 meters/sec	
direction	10.0 minutes of arc	(U)

General Electric Company (11) made the following independent accuracy estimates for the Mars injection:

Azimuth angle	1.7 mr = 6 minutes of arc
Flight Path Angle	1.7 mr = 6 minutes of arc
Velocity Magnitude	Less than 0.65 ft/sec ~~(S)~~

The two estimates are in good agreement with regard to the angular accuracies. However, there is considerable difference in the velocity error estimate: 0.65 ft/sec versus approximately 10 ft/sec. The G. E. estimate of 0.65 ft/sec indicates an accuracy far in excess of velocity cutoff errors in their ballistic missiles and in other space probes - which usually runs in the order of 50 ft/sec. (9) (10) Consequently, the author prefers the estimate derived from the Soviet statement. ~~(S)~~

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