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JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM
312.4-56
June 11, 1964

TO: T. W. Hamilton, V. C. Clarke, Jr., P. K. Eckman, M. A. Minovich, F. Sturms

FROM: E. Cutting

SUBJECT: Proposal for a Trajectory Study of a Low Energy Mercury Mission

This memo describes a proposed trajectory-oriented study of a Mercury mission using an Earth-Venus-Mercury trajectory rather than a direct Earth-Mercury transfer. With this multiple encounter trajectory, useful payloads can be achieved with a standard Atlas-Centaur. In many respects the mission is less difficult than Mariner C. Background information is given in the discussion below. The Ground Rules of the study are then listed. These rules are fairly restrictive in order to limit the scope of the study. It is believed that the ground rules can easily be achieved, and it will be noted that they will result in a quite conservative design. The study is divided into three areas, each the responsibility of one man:

Conic Trajectory Studies, M. A. Minovich, 1 man-month
Integrated Trajectory Studies, F. Sturms, 1/2 man-month
Guidance and Subsystem Studies, E. Cutting, 1/2 man-month

Computer production costs are estimated at $1500. References are listed at the end of this memo. The study will result in a Section 312 Technical Memo, to be published by September 1, 1964. If the results meet our expectations, the TM will be republished as an external report. Comments on this proposal are requested.

DISCUSSION

An unmanned Mercury flyby mission could accomplish several useful scientific objectives. Among these are: measure fields and particles at radii of .4 - .7 AU from the sun, measure the surface temperature of the cold side of Mercury, improve our knowledge of the mass of Mercury, etc.[1] Unfortunately, however, direct transfers from Earth to Mercury require C_3's in excess of 40 km^2/sec^2 [2] and thus large boost vehicles are required[3]. An alternative to the direct transfer is the multiple encounter trajectory[4], in which the spacecraft passes close to Venus where it is deflected and continues to Mercury. The advantage of this multiple encounter trajectory is that geocentric C_3's are reduced to about 13 km^2/sec^2 allowing the use of less expensive launch vehicles such as a standard Atlas-Centaur. Attendant disadvantages are increased flight times and error sensitivities[5]. We have made a preliminary study of these factors and conclude that the Earth-Venus-Mercury mission is worthy of further investigation. A proposed trajectory oriented mission study is outlined below.

GROUND RULES

(1) Use Earth-Venus-Mercury transfer such as discussed in references 4 and 5.

(2) Firing period to be 1970 Venus opportunity.

(3) AMR launch at azimuths of 90 - 114°.

(4) Standard Atlas-Centaur with parking orbit capability.

(5) Standard trajectory aiming point at Venus to be no closer than 3000 km from surface. (distance of closest approach)

(6) No other restrictions on Venus aiming point (e.g. occultations of Earth, Sun, and Canopus are allowed).

(7) Standard trajectories to be targetted for constant arrival time at Venus (approximately November 27, 1970).

(8) Spacecraft to flyby Mercury.

(9) Standard trajectory aiming point at Mercury to be about 50,000 (?) km from Mercury and on cold side.

(10) Aiming point and arrival time at Mercury to be approximately the same throughout firing period.

(11) No other restrictions on Mercury aiming point.

(12) Desired launch period is about 30 days.

(13) Desired payload weight is about 1500 lbs on standard Atlas-Centaur.

(14) Flight time to be about 150 days.

(15) Maximum communication distance to be about 150×10^6 km.

(16) Earth based radio guidance only (no vehicle based observations).

(17) No more than 3 maneuvers, if possible.

acc'y of mass det'n?
Solar pressure effects on acc'y?

CONIC TRAJECTORY STUDIES

(1) Using HECON compute the following Venus-Mercury trajectories

initial launch day, Oct. 16, 1970
launch day step, 1 day
final launch day, Jan. 16, 1971
initial flight time, 40 days
flight time step, 2 days
final flight time, 150 days

Obtain save tape, microfilm and copyflow of trajectory data.

(2) From the HECON trajectories, obtain contours of C_3 relative to Venus for the following variables plotted against launch date

Venus-Mercury flight time
declination of asymptote leaving Venus
right ascension of asymptote leaving Venus.

These curves are analogous to Fig. 10-1, 10-4, 10-5 in reference 6.

(3) Using the data obtained in (1) and (2) together with the Earth-Venus design curves in reference 6 and the Earth-Venus trajectory data in reference 7, develop a logical design procedure for Earth-Venus-Mercury transfers.

(4) Use the design procedure developed in (5), to carry out the design for the 1970 mission according to the above ground rules.

(5) For the design in (4), obtain plots of the following variables against Earth launch day.

declination and right ascension of incoming Venus asymptote
declination and right ascension of outgoing Venus asymptote
impact parameter at Venus
$\overline{B}\cdot\overline{T}$ and $\overline{B}\cdot\overline{R}$ at Venus
C_3 relative to Earth

(6) From the last curve in (5) obtain approximate launch period and payload.

(7) From the selected trajectories and reference 7, determine Earth injection loci.

INTEGRATED TRAJECTORY STUDIES

(1) Check the inclusion of Mercury is a target body in the Space Trajectories program[8].

(2) Select 3 representative trajectories from the firing period determined in (6) of the Conic Trajectory Study. If possible, one of these should be the same Earth-Venus-Mercury trajectory studied in reference 5.

(3) Develop a method of targeting the integrated trajectories according to the ground rules specified above.

(4) Target the trajectories and make the following plots (all three trajectories on each plot)

range from the Earth versus time
range rate from the Earth versus time
sun-probe distances versus time
earth-probe-sun angle versus time
cone angle of earth versus time
clock angle of earth versus time
cone angle of Canopus versus time
clock angle of Canopus versus time
projection of trajectory on ecliptic plane (separate plots)
celestial latitude versus time
celestial longitude versus time

(5) Using TAIM obtain plots for each trajectory of

aiming zones at Venus
aiming zones at Mercury

(6) Compare integrated and conic trajectories particularly regarding C_3 relative to Earth and $\overline{B}\cdot\overline{T}$, $\overline{B}\cdot\overline{R}$ at Venus

(7) Study linearity of important differential coefficients such as those used in targeting and in guidance studies.

(8) Estimate effect of uncertainty in Mercury ephemeris on accuracy of trajectory calculations.

GUIDANCE AND SUBSYSTEM STUDIES

(1) Study possible scientific mission objectives, and corresponding trajectory constraints by consulting references 1, 9 and JPL space scientists.

(2) Determine major problems in subsystem areas by consulting JPL specialists

temperature control
power
communications
guidance and control
propulsion

(3) Obtain differential coefficients from HECON and Space Trajectories runs using trajectories from other two studies.

(4) Obtain estimates of orbit determination accuracy from references 10, JPL specialists and ODP runs.

(5) Perform an approximate guidance analysis to obtain estimates of guidance accuracy and fuel requirements subject to ground rules,

a. first maneuver shortly after injection to correct booster errors

b. second maneuver shortly before Venus arrival to correct execution errors and physical constant errors

c. third maneuver shortly after leaving Venus to correct Venus arrival errors propagating into Venus outgoing asymptote errors

(6) Use TAPP 2 to verify results of (5) on one of the integrated trajectories obtained in the Integrated Trajectory Study.

(7) Investigate effect of physical constant errors neglected in (5) and (6).

REFERENCES

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(4) Minovich, M. A., The Determination and Characteristics of Ballistic Interplanetary Trajectories Under the Influence of Multiple Planetary Attractions, TR 32-464, JPL, 10/31/63

(5) Sturms, F., Error Analysis of Multiple Planet Trajectories, SPS 37-27 Vol. IV, JPL, to be published.

(6) Clarke, V. C. etal, Design Parameters for Ballistic Interplanetary Trajectories Part 1. One Way Transfers to Mars and Venus, TR 32-77, Part 1, JPL, 1/16/63

(7) Clarke, V. C. etal, Earth-Venus Trajectories, 1970, TM 33-99, Vol. 5 Part B, JPL, 10/1/63

(8) Cutting, E. and Sturms, F., Temporary Fix to Allow Computation of Trajectories to Mercury on the Space Trajectories Program, RFP 312-292, JPL, 6/5/64

(9) Sander, W., The Planet Mercury, The Macmillan Company, New York, 1963

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