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JET PROPULSION LABORATORY *California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103*

July 22, 1974

Dr. Norriss S. Hetherington
18 Strong Hall
History Department
University of Kansas
Lawrence, Kansas 66044

Dear Dr. Hetherington:

As a result of recent letters written to you and others by Dr. Michael A. Minovitch regarding the accuracy of certain portions of your manuscript entitled, "Gravitational Thrust: The Development and Application of an Idea," I find it necessary to amplify and clarify the comments I made to you on your initial draft. These were made in a letter to you on October 16, 1972, and are noted as reference 20 in your final manuscript.

The question deals with the extent of my work on gravity-assist trajectories and Dr. Minovitch's assignment by me when he began working at the Jet Propulsion Laboratory in June, 1961. I submit for your examination the attached extracts from two JPL Research Summaries. The first, No. 36-9, describes a portion of my activities from the period April 1 to June 1, 1961, and the second, No. 36-10, covers the following bimonthly period, June 1 to August 1, 1961.

These Research Summaries reflect the fact that I was working on round trip ballistic gravity-deflected trajectories and that I was planning further work in that area prior to the time that Dr. Minovitch began employment at JPL. That I intended to pursue further work in this area is indicated by another JPL Research Summary, No. 36-11, covering the period August 1 to October 1, 1961. That document shows that another member of my group, Mr. William E. Kirhofer, had done a comprehensive analysis of gravity-deflected trajectories using the Moon as the deflecting body.

I wish to make it very clear that I did not assign Dr. Minovitch any work on multiple gravity-assist trajectories other than round trip trajectories between Earth and another planet. It is to Dr. Minovitch's

Telephone 354-4321 *Twx 213-449-2451*

great credit that he extended and generalized the problem to gravity-assisted transfers between n bodies in any order. My statement to you in my letter of October 16, 1972, "The substitution of a planet other than Earth for the second planetary encounter was obvious." was transformed in your manuscript into, "... and the extension of the idea to multiple-planet trajectories was obvious." This transformation, plus my use of the trite word, "obvious," conveys an incorrect impression that it was my idea to extend the problem beyond round trip trajectories at the time. Indeed, it was not my idea, but Dr. Minovitch's.

Sincerely,

Victor C. Clarke, Jr.

Victor C. Clarke, Jr.
Mariner 10 Mission Analysis
and Engineering Manager

VCCJr:bs
Att.

COPY 1

SYSTEMS DIVISION

II. Systems Analysis

A. Trajectory Analysis

V. C. Clarke

1. Interplanetary Trajectories

As reported in *RS 36-8*, a computer study is in progress to determine the characteristics of ballistic interplanetary trajectories from Earth to Mars, Venus, Mercury, and Jupiter. The computations for Venus from 1962 to 1970, for Mars from 1962 to 1977, for Mercury from October 1967 to January 1969, and for Jupiter from December 1969 to February 1970 are now complete. A table of minimum energy transfers was published in *RS 36-8*. Final additions to that table are given in Table 1. These trajectories have been computed using actual planet positions obtained from an ephemeris tape. Thus, inaccuracies arising from assuming coplanar, circular motions of the planets are nonexistent.

Selected parameters of the trajectories have been saved on magnetic tapes. These tapes are being used to generate graphs of the parameters on an automatic plotting machine. The results of this study, with about 200 graphs, will be reported in Reference 7. Publication target date is September 1961.

A second phase of the study has begun with the computation of return ballistic trajectories from Mars and Venus to Earth. The results of these computations will also be saved on magnetic tape, and graphs will be prepared. In addition, the return trajectories will be combined with the Earth-to-target planet trajectories in a merging program to obtain round trip transfers. These transfers will include both ballistic flyby and stopovers of various duration at the planet. Completion of this phase of the study is projected to November 1961.

2. Out-of-Ecliptic Trajectories

A study is nearing completion of a special class of trajectories in which a space probe is launched from Earth in a direction perpendicular to the ecliptic plane, flies above (or below) the plane for a period up to 6 months, and finally returns to Earth. A cursory look at such trajectories from two-body (Sun-probe) mechanics indicates that the distance above the ecliptic that can be

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1. Interplanetary Trajectories

As reported in two previous *Research Summaries (RS 36-8, 36-9)*, a computer study is in progress to determine the characteristics of ballistic interplanetary trajectories from Earth to Mars, to Venus, to Mercury, and to Jupiter. The results of this study will be reported in Reference 7. This report will contain the theory and analysis of three-dimensional ballistic interplanetary transfer. In addition, graphs of 18 pertinent trajectory parameters for each of six launch intervals for Venus from 1962 to 1970 and eight launch intervals to Mars from 1962 to 1977 will be illustrated. At present, all the computation and about 30% of the graphs have been completed. Publication date has been revised to November 1, 1961.

As part of the continuing effort in ballistic interplanetary trajectory analysis, a library of round-trip trajectories, both flyby and stopover, will be computed. A computer program is now being written to accomplish this phase of the analysis. A formal publication on the results of the round-trip trajectories should be ready about the end of 1961.

2. Out-of-the-Ecliptic Trajectories

In *RS 36-9*, preliminary results of a study of a special class of trajectories, called "Out-of-Ecliptic Trajectories," were given. For this class of trajectories, the primary motion is normal to the ecliptic plane, or along an Earth-centered radial direction which has a declination of about 66.5 degrees and a right ascension of about 270 degrees. An Earth-based observer would, at first, observe a space probe launched on this type of trajectory traveling outward along the radial direction with decreasing speed until it came to rest. The maximum distance of outward travel (or altitude above the ecliptic) would be proportional to the hyperbolic-excess speed (i.e., injection energy). After reaching maximum distance at zero-speed, the probe would turn around and return to Earth along the same radial, but with increasing speed. An illustration of the speed profiles for various hyperbolic-excess speeds is shown in Figure 1. The independent variable in this figure is time of flight from injection. From this figure it can be seen that the total flight time is also dependent on the hyperbolic excess speed, varying from 128 days for $V_h = 0.1$ km/sec to 182 days for $V_h = 3$ km/sec.

A Sun-based observer, who sees the Earth revolving around him once per year, would notice the probe rise from the Earth and fly directly above it with increasing