D5-12 128

N87-17727

LIBRATION-POINT STAGING CONCEPTS FOR EARTH-MARS TRANSPORTATION

Robert Farquhar, Goddard Space Flight Center
and
David Dunham, Computer Sciences Corporation

ABSTRACT

The use of libration points as transfer nodes for an Earth-Mars transporation system is briefly described. It is assumed that a reusable Interplanetary Shuttle Vehicle (ISV) operates between the libration point and Mars orbit. Propellant for the round-trip journey to Mars and other supplies would be carried from low Earth orbit (LEO) to the ISV by additional shuttle vehicles. Different types of trajectories between LEO and libration points are presented, and approximate delta-V estimates for these transfers are given. The possible use of lunar gravity-assist maneuvers is also discussed.

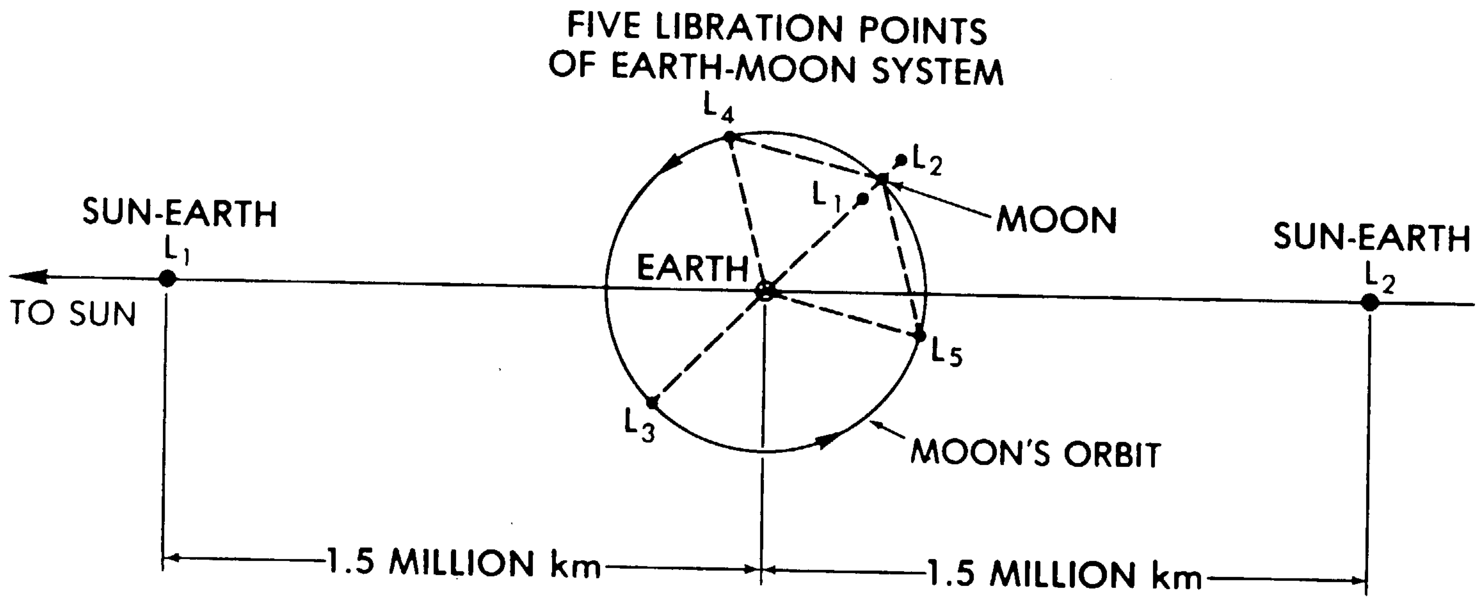
LIBRATION-POINT STAGING CONCEPTS FOR EARTH-MARS TRANSPORTATION

The existence of five positions of equilibrium in the gravitational field of an isolated two-body system (e.g., Earth-Moon or Sun-Jupiter) is well known. As shown by the French mathematician, J. Lagrange in 1772, these "libration points" have the interesting property that if a third body were placed at one of them with the proper velocity, the centripetal acceleration of the third body would be perfectly balanced by the gravitational attractions of the two primary bodies. Three points are situated on a line joining the two attracting bodies, while the other two form equilateral triangles with these bodies. Although the three collinear points are inherently unstable and the two triangular points are only quasi-stable, the stationkeeping cost to maintain a spacecraft at or near one of these points for an extended period of time is very small [1].

A total of seven libration points are located in the Earth's neighborhood (see Figure 1). Five of them are members of the Earth-Moon System and two belong to the Sun-Earth System. In the reference frame shown in Figure 1, the Sun-Earth line is fixed and the Earth-Moon configuration rotates around the Earth. From the standpoint of potential applications to astronautics, the L1 and L2 points of both systems are noteworthy. It is anticipated that some or all of these points will be

FIGURE 1

LIBRATION POINTS IN THE VICINITY OF THE EARTH



utilized as transportation nodes in future manned expeditions to the Moon and Mars [2].

Spacecraft trajectories from low Earth orbit (LEO) to collinear libration points are difficult to analyze because these trajectories spend considerable time in a region where the gravitational effects of the two primary bodies are comparable. In this situation, standard analytic approximations such as the patched-conic technique break down, and numerical integration must be employed.

Figure 2 depicts fuel-optimal examples of the two principal classes of transfers between LEO and the Sun-Earth L1 point. Optimality has been determined on the basis of the terminal maneuver at L1 because the injection delta-V at LEO is virtually identical for all cases. Although the delta-V requirement is higher for the fast transfer, the flight time is less than one-third of that needed by the slow transfer. Smaller delta-V costs can be achieved by using transfers with much longer flight times and/or by including a lunar gravity-assist maneuver. However, a more effective way to reduce the delta-V cost is to simply target to an orbit around the L1 point instead of the point itself [3]. This method was used to place the International Sun-Earth Explorer-3 (ISEE-3) spacecraft into a large "halo orbit" around the L1 point [4] (see Figures 3 and 4). The retro delta-V for ISEE-3 was essentially the sum of delta-V2 and delta-V3 (i.e., 36.3 m/sec).

Two types of trajectories between LEO and the Earth-Moon L2 point are shown in Figure 5. In both cases the delta-V at LEO is roughly 3.15 km/sec. Notice that the two-impulse transfer is almost 5 days faster than the three-impulse example. However, the retro delta-V for the three-impulse transfer is smaller by about 900 m/sec. This comparison demonstrates that the identification of an efficient trajectory to or from the vicinity of a libration point can be a rather subtle exercise. The use of a powered lunar swingby to reduce the retro delta-V at L2 was certainly not obvious.

The three-impulse trajectory of Figure 5 is a key element of a lunar transporation concept that uses the Earth-Moon L2 point as a staging location. In this concept, a large chemical orbit transfer vehicle (OTV) carries payloads between LEO and L2 point. At the L2 point, the payload is transferred to a smaller OTV that operates between L2 and low lunar

FIGURE 2

TRAJECTORIES TO THE SUN-EARTH L_1 LIBRATION POINT

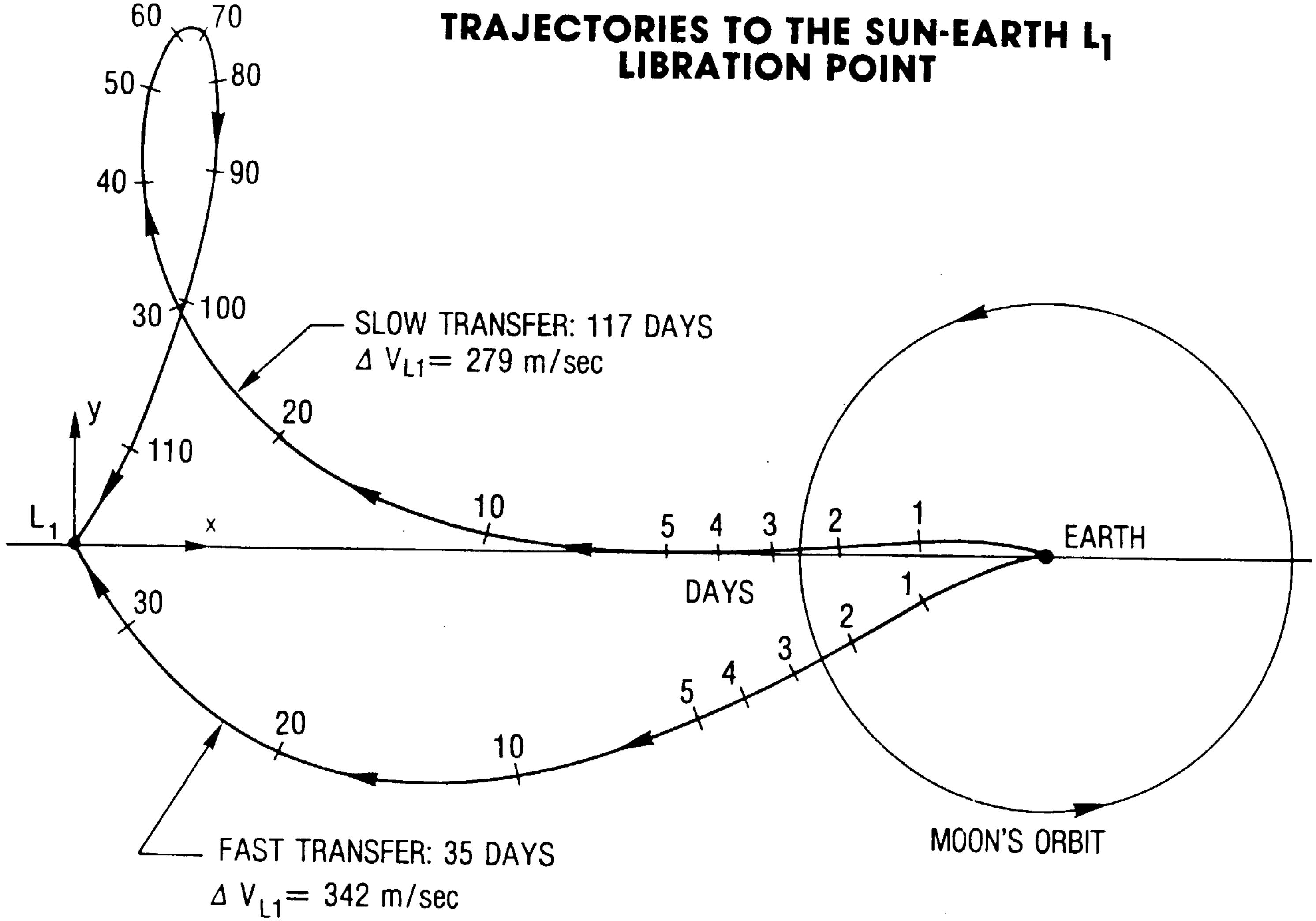


FIGURE 3

HALO ORBIT AROUND SUN-EARTH LIBRATION POINT

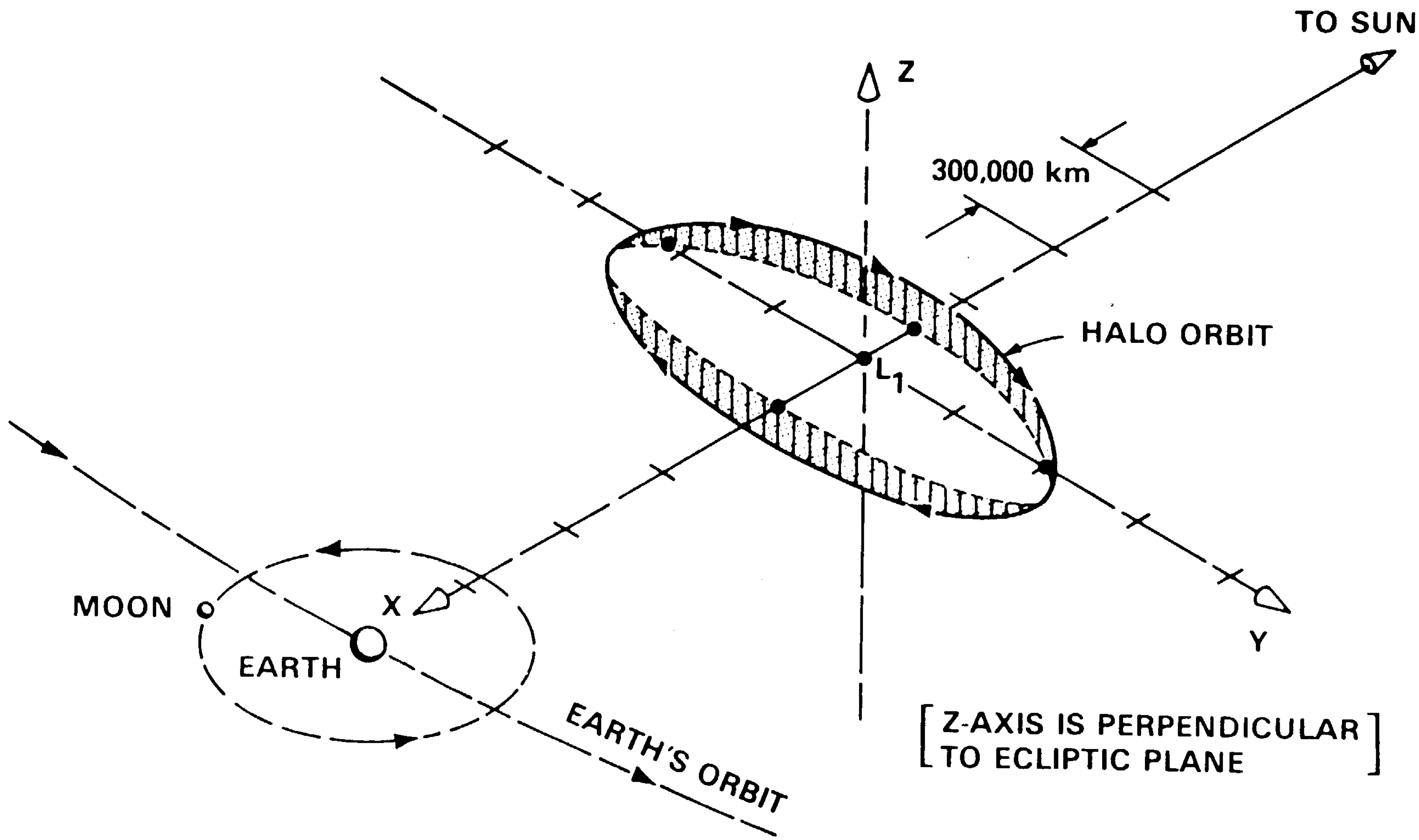


FIGURE 4

ISEE—3 TRANSFER TRAJECTORY

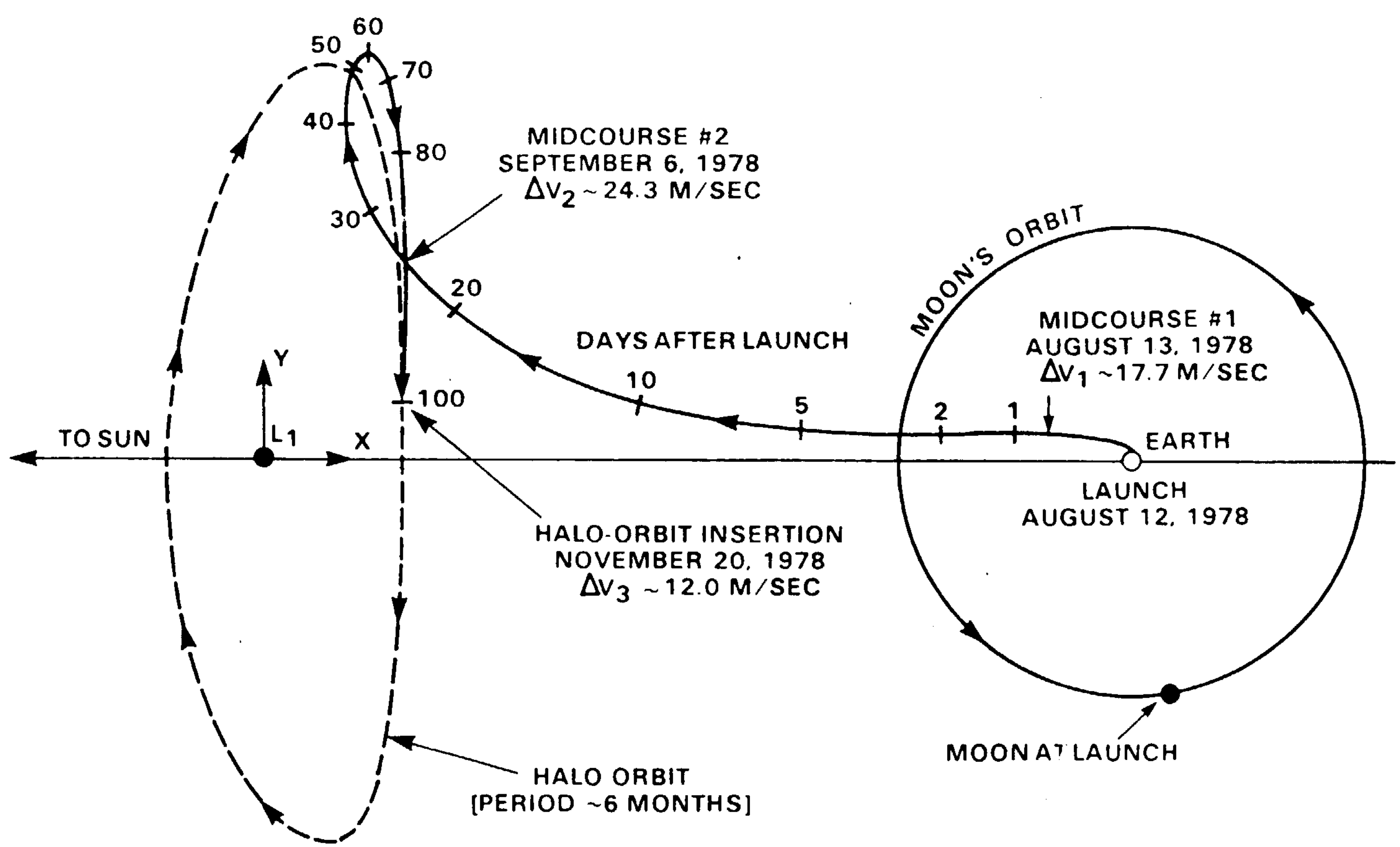
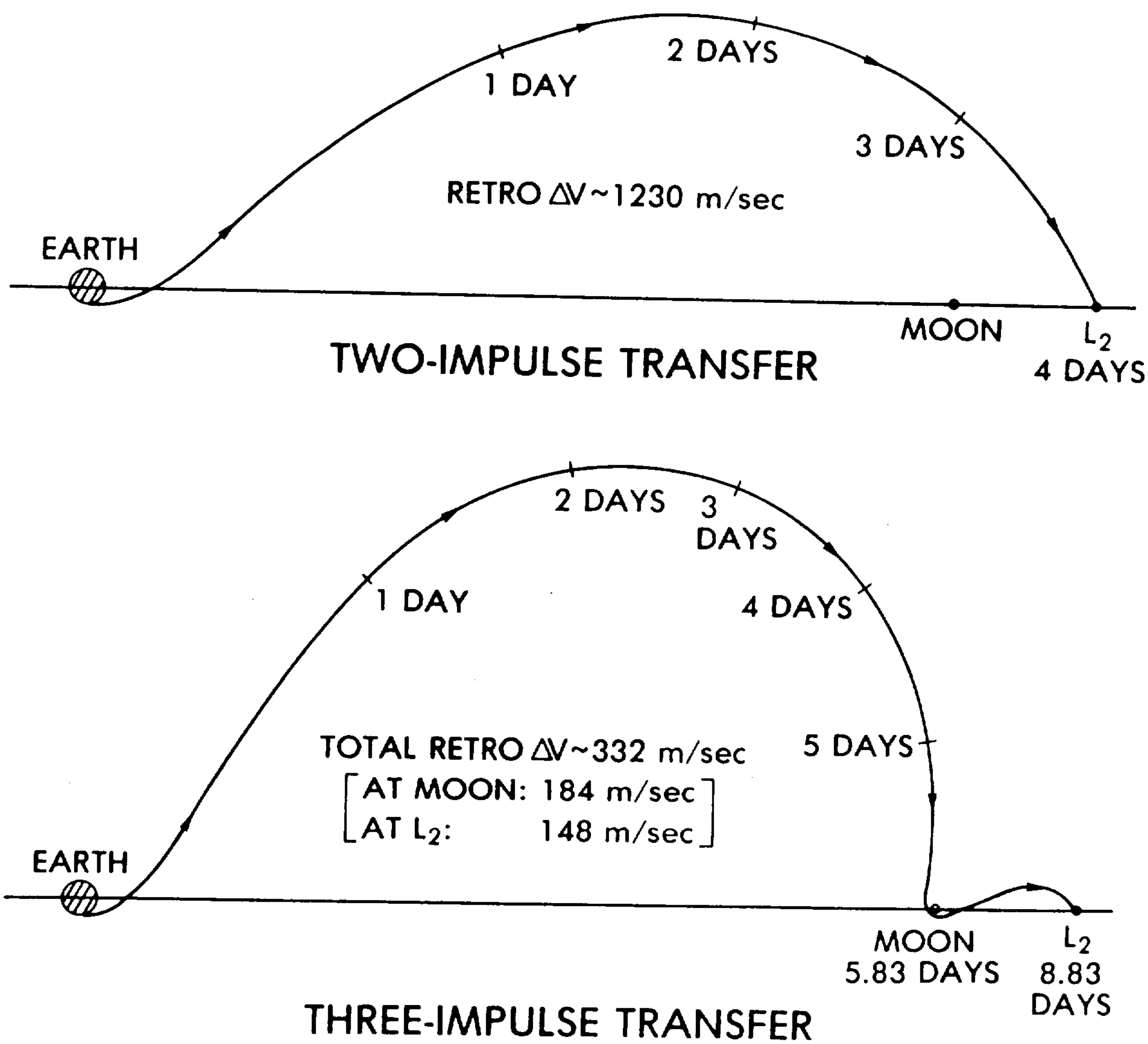


FIGURE 5

TRAJECTORIES TO VICINITY OF EARTH-MOON L_2 POINT



orbit (LLO). Comparison of this scheme with the more conventional techniques of using a single OTV between LEO and LLO showed that a significant performance advantage could be gained by using L2 staging [5].

Libration point staging may also be advantageous for Earth-Mars transportation. In this case, there are six potential locations for transfer nodes. They are the L1 and L2 points of the Sun-Earth, Earth-Moon, and Sun-Mars Systems. One or all of these points could be used. The L1 and L2 points of the Sun-Mars system average about 1.08 million kilometers from Mars, but their distance varies by more than 10% due to the eccentricity of Mars' orbit.

For instance, consider a reusable stage that is stationed in the vicinity of the Sun-Earth L1 point. This vehicle would operate between the L1 point and Mars orbit (or possibly a Sun-Mars libration point). The transfer would be initiated by applying a small impulse at L1 to bring the interplanetary shuttle vehicle (ISV) close to the Earth. Near perigee, a larger delta-V maneuver would be used to place the ISV into the proper trans-Mars trajectory. The ISV would also be used to achieve Mars orbit (either by aerocapture or propulsive maneuver). A reverse procedure would be used to return the ISV to the Sun-Earth L1 point. Resupply of the ISV would be accomplished by OTV's that travel between the L1 point and LEO. In all likelihood, these would be the same OTV's that would be used for lunar transportation.

Preliminary delta-V estimates for transfers that begin or end in a halo orbit around the Sun-Earth and Earth-Moon libration points (L1 and L2) are given in Figure 6. The second delta-V for the escape case is applied near the Earth, at the perigee of a highly eccentric transfer orbit whose initial apogee is at the departure halo orbit. These data can be used to obtain a coarse measure of the performance of the libration-point staging concept. However, as noted earlier, delta-V costs for transfers to libration-point orbits are sensitive to variations in flight time and the type of trajectory that is employed. It is hoped that a more accurate and complete summary of these delta-V costs will be available in the near future.

Lunar gravity-assist maneuvers can be used to improve performance, reduce flight times, and ease launch-window restrictions [6, 7, 8].

4762–86

FIGURE 6

PRELIMINARY ΔV ESTIMATES (M/SEC)

- LOW EARTH ORBIT → HALO ORBIT

	SUN–EARTH	EARTH–MOON
ΔV_1	3200	3150
ΔV_2	50	300

- HALO ORBIT → ESCAPE [$C_3 \sim 10\ KM^2/SEC^2$]

	SUN–EARTH	EARTH–MOON
ΔV_1	50	300
ΔV_2	500	550

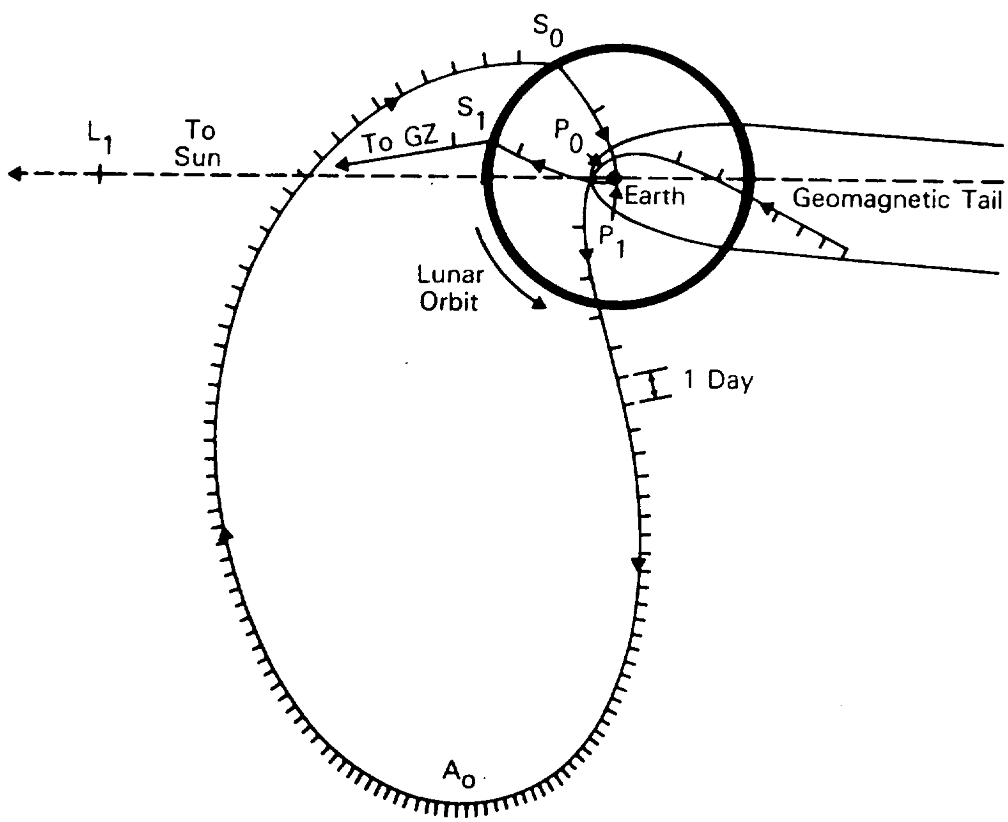
- OTHER TRANSFERS

LUNAR ORBIT → SE HALO	850
LUNAR ORBIT → EM HALO	750
SE HALO → EM HALO	300

These maneuvers are expected to play an important role in shaping the ISV and OTV flight profiles. An example of how lunar swingby maneuvers can be used to augment orbital energy is shown in Figure 7. Notice that the two lunar maneuvers have increased the C3 value from -0.5 to +4.5 km2/sec2. It may be possible to add a third swingby maneuver to attain sufficient energy to reach Venus and then on to Mars. The flight times for this scenario might be too long for crew transfers, but should be satisfactory for cargo missions.

The main idea of the transportation concept outlined here is to use the libration point region as a stepping stone to get to Mars. By starting the Mars journey from a location at the rim of the "energy well" instead of LEO, the delta-V requirement for the ISV is considerably lower. However, performance is not the only relevant factor. Tradeoffs involving flight time, launch-window flexibility, rendezvous operations, abort modes, propulsion options, etc. should be included in comparison studies of alternative mission modes for Earth-Mars transportation. A thorough system study of the competing concepts is needed to identify a baseline plan.

FIGURE 7
HYPERBOLIC DOUBLE LUNAR SWINGBY TRAJECTORY TO COMET GIACOBINI-ZINNER



EVENT	1984 DATE	G.M.T.	DISTANCE	SHADOW	C_3 (km/sec)^2
P_0	Sept. 5		9.4 R_e		
A_0	Oct. 24		307 R_e		
S_0	Dec. 17	16^h 23^m	2283 km	46^m	−0.46
P_1	Dec. 19	10 23	1.8 R_e	29	+1.20
S_1	Dec. 21	4 20	1800 km	29	+4.49

REFERENCES

[1] Farquhar, R. W., "The Control and Use of Libration-Point Satellites", NASA TR R-346, September 1970. (Originally published as Stanford University Report SUDAAR-350, July 1968).

[2] Farquhar, R. W., "Future Missions for Libration-Point Satellites," Astronautics and Aeronautics, Vol. 7, No. 5, May 1969.

[3] Farquhar, R. W., Muhonen, D. P., and Richardson, D. L., "Mission Design for a Halo Orbiter of the Earth". Journal of Spacecraft and Rockets, Vol. 14, No. 3, March 1977.

[4] Farquhar, R. W., Muhonen, D. P., Newman, C. R., and Heuberger, H. S., "Trajectories and Orbital Manuevers for the First Libration-Point Satellite", Journal of Guidance and Control, Vol. 3, No. 6, November-December 1980.

[5] Farquhar, R. W., "The Utilization of Halo Orbits in Advanced Lunar Operations", NASA TN D-6365, July 1971.

[6] Farquhar, R. W., and Dunham, D. W., "A New Trajectory Concept for Exploring the Earth's Geomagnetic Tail", Journal of Guidance and Control, Vol. 4, No. 2, March-April 1981.

[7] Special Issue on ISEE-3/ICE Mission, Journal of the Astronautical Sciences, Vol. 33, No. 3, July-September 1985.

[8] Ross, D. J., "Material Capture by Double Lunar Gravity Assist", AIAA Paper 80-1673, August 1980.