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The Role of the Cis-Lunar Libration Point in Lunar Operations

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The purpose of this presentation is to define the advantages which result from the use of the cis-lunar libration point L₁ as place of departure for descent to the Moon, as parking place for the Command Module and as place of rendezvous after take-off of the Lunar Landing Vehicle (LLV) from the Moon in regard to simplifying operations in lunar space and increasing the chances of success of lunar missions.

The Earth-Moon System contains five points where the initial forces are in exact balance with the gravitational forces from Earth and Moon and which remain in fixed position relative to the Earth-Moon configuration. These are the so-called libration points. The uniqueness of these positions has made them the subject of a number of studies beginning with those of La Grange in the 18th century.

For the restricted 3-body model, considering only Earth and Moon rotating around their barycenter, the location of the libration points is shown in Fig. 1. The orbits of the triangular points L₄ and L₅ are ellipses similar to that of the Moon's orbit, whose axes are tilted 60° from that of the Moon. The orbits of the co-linear points L₁, L₂, and L₃ are ellipses concentric with that of the Moon. It should be noted that the triangular points are basically stable, whereas the co-linear points are basically unstable positions. The term "unstable" means that any displacement of a body from the exact location of the libration point will result in an ever-increasing displacement away from the point.

The forces acting on a body at the so-defined libration points are balanced only if the effect of the Sun is neglected (3-body system). If the effect of the gravitational field of the Sun and the motion of the Earth-Moon System around the Sun is taken into account, (4-body system) this balance is disturbed. It appears that the two conditions of constant celestial configuration and exact force balance are incompatible in the Earth-Moon-Sun system.

In context with the initially stated objective we can disregard this definition problem and address ourselves to determining the magnitude of the force imbalance at the 3-body libration points and to determining the motions of a spacecraft relative to these points. Fig. 2 shows the radial accelerations due to 4-body conditions acting on a vehicle positioned at the 3-body libration points. The accelerations are plotted for L₁ and L₄ in terms of standard terrestrial acceleration "g" as function of time in terms of Moon-phases. It should be noted that this imbalance is very small and can easily be counteracted by a propulsion device. Weight addition required for station-keeping is a function of spacecraft weight, time on station, and propulsion method. In terms of velocity increment the station-keeping effort amounts to an average of 10 ft/sec/day or 300 ft/sec for one month on station. An ion engine can do this station-keeping job with an additional weight in the order of 1% of the total vehicle weight for about one year.

If we do not use station-keeping, the spacecraft drifts out of position even in the so-called stable cases. Typical trajectories are shown in Fig. 3 and 4. From these diagrams and the above discussion, we can conclude in unscientific terms:

- The degree of stability of the triangular points L₄ and L₅ is not as great as expected.
- The degree of instability of the co-linear points L₁, L₂, and L₃ is not as great as feared and ample time is available for corrective action in form of
This latter conclusion is significant in evaluating the operational usefulness of the libration points. In this context we are interested not in the exact points and their theoretical stability but rather in volumes of Earth-Moon Space in which a spacecraft can be held in fixed position relative to the lunar surface with a minimum of propulsive energy, in other words, play the role of a synchronous satellite of the Moon. In fact, a more detailed analysis will show that the point or rather flight path of minimum station-keeping energy is not L_1 but slightly off.

For the case of L_1 we have plotted in Fig. 5 the velocity increment in ft/sec/day required to keep the spacecraft in the vicinity of L_1, as a function of interval between corrective impulses, and in Fig. 6 some typical trajectories in the vicinity of L_1. Through suitable optimization this energy can be further reduced.

Up to this point we have discussed the properties of the libration points and approaches to cope with the peculiarities of these points in space. We now would like to discuss the operational advantages offered by the L_1 position. This location appears to be attractive for several reasons:

- Of the five libration points, L_1 is closest to the Moon at an average distance of 31,000 N.M.
- The spacecraft can be kept in the vicinity of L_1 at the cost of less than ΔV = 10 ft/sec/day in spite of the inherent instability of the position.
- The position is well-defined for practical purposes in spite of the mathematical difficulties and can be determined with sufficient accuracy with state-of-the-art means.
- A spacecraft in L_1 is in fixed position to the near side of the Moon playing the role of a synchronous satellite.

In the proposed concept a trip made from the Earth to the Moon and back would be made in the following steps: The combined spacecraft; namely, Command Module (CM) and Lunar Landing Vehicle (LLV), will be placed into the vicinity of L_1 with the additional expenditure of 1500-2000 ft/sec over the lunar escape velocity. After reaching L_1 the LLV is detached and departs whenever ready for the desired place on the near side of the Moon with an additional propulsive effort of ΔV = 500-1000 ft/sec. During the approach the landing area is always in full view of both LLV and CM. The duration of stay on the Moon is completely at the discretion of the crew and limited only by considerations of safety and the consumption rate of expendables. After accomplishing its mission, the LLV takes off and proceeds directly to the waiting Command Module at L_1. During all this time, descent, stay on the Moon, and ascent, there is always line-of-sight connection between LLV and CM. Rendezvous and docking in the vicinity of L_1 are conducted in an environment where the effect of gravitation and spacecraft motion are very small and practically uncoupled simplifying the job of the pilots during the maneuver. After completing rendezvous, the Command Module disorbits for return to Earth with about 1500-2000 ft/sec and with complete freedom of timing.

The main advantages of this avenue of approach to lunar travel are:

- Unlimited window for the start of LLV to the Moon. There is no need to have functional countdown coincide with a certain time and position in lunar orbit.
- Unlimited launch window for return to LLV from the lunar surface.
- Full-time communications as well as optical and RF tracking from L_1 to the near side of the Moon simplify greatly the navigation problem by permitting a more active role of the pilot and a considerable reduction in dependence on earth-based computer and support operation.
- Increased flexibility for beginning return flight to Earth.
- Landings far off the lunar
equator can be made without increased propulsion requirements or without imposing operational restrictions, something which cannot be done with rendezvous in low lunar orbit without changes in present LEM.

Each of these advantages is at least very desirable. Unfortunately, it is difficult to express the degree of improvement in simple numerical terms such as lb, ft/sec, or similar units, without having to make use of subjective value judgments introducing individual opinions. In sum total, however, it is hard to disagree with the conclusion that these individual improvements add up to increase the chances of mission success or crew survival by a factor of 2 to 4.

Of course, this improvement does not come without a cost: The travel time of the LLV between begin of descent and landing on the Moon as well as return trip is, in the order of 10-16 hours, much longer than from a low lunar orbit. Also, the total velocity increment required for LLV propulsion is about 35% higher than required for the case of the operation conducted from low lunar orbit. This is partially compensated by a decrease of ΔV required for the Command Module. In other words the Command Module does not have to descend into the lunar gravity well and therefore requires less propellant weight, but that part which does, the Lunar Landing Vehicle, is heavier than the present LEM and therefore requires more propulsive energy. If Hydrogen-Oxygen is used for the descent down to the Moon, the total weight accelerated to earth escape velocity by Saturn 5 is only slightly higher than that required for low lunar orbit rendezvous. In fact, if the gains obtainable from simplifications of operations and from fuller utilization of the crew are translated into decreased safety margins for propellant loading, there seems to be a good chance that a lower total weight will result at a superior mission reliability.

If we want to explore the Moon beyond our first high-risk steps, it is mandatory that we devise the safest travel method conceivable. Whether or not the use of the cis-lunar libration point in the fashion described is the best method boils down to the question of what value should be assigned to:

- Widening of launch window for LLV both to and from the Moon.
- Freeing the pilot from complete dependence upon earth-based computer by simplifying navigation and rendezvous control.
- Full-time line-of-sight connection between the spacecraft and LLV.

After acquiring more experience as to man's capabilities and usefulness in space, we will be in a better position to provide answers to these questions. However, if we equate simplicity with reliability, we cannot escape the conclusion that this method of lunar travel deserves a good deal of attention as a safer way to get there.

Acknowledgement

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FIGURE 1  Libration Points in the Earth-Moon System

FIGURE 2  Acceleration at \( L_1 \) and \( L_4 \) due to 4-Body Condition
FIGURE 3  Typical Trajectory from L₁ with Initial Relative Velocity = 0

FIGURE 4  Typical Trajectory from L₄ with Initial Relative Velocity = 0
FIGURE 5  Trajectories near \( L_1 \)

FIGURE 6  Optimum Cycle Operation