

A Halo-Orbit Lunar Station

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Its many advantages compared with the initially proposed lunar-orbit station argue a reassessment of present plans in the form of definitive tradeoff studies

In the summer of 1969 the President's Space Task Group proposed a comprehensive "integrated Program Plan" for lunar exploration in the 1980s and beyond.¹ A key item in this plan foresees establishing a space station in the vicinity of the Moon. The Integrated Program Plan specifies that this space station be placed in a 60-n. mi. polar lunar orbit. However, for reasons that will be discussed here, it may very well be better to locate the lunar space station in a "halo orbit" around the translunar libration point, L_2 .

The halo orbit has previously been considered as a possible location for a lunar far-side data-relay satellite.² As shown in chart (F-1) on page 60, a relay satellite following a halo trajectory will always maintain line-of-sight contact with the Earth and the Moon's far side. Moreover, the entire halo orbit, when viewed from the Moon's surface, would subtend an angle of only 6.2 deg. Of course, station-keeping will be required to keep a satellite in halo orbit, but the control techniques are extremely simple and the annual fuel expenditure is quite reasonable ($\Delta V \sim 400$ fps per yr). Detailed control analyses for halo satellites exist.³⁻⁴

The Integrated Program Plan calls for a fully reusable Earth-Moon transportation system, the principal hardware elements of it being a Trans-lunar Shuttle (TLS), a Lunar-Orbit Space Station (LOSS) or Halo-Orbit Space Station (HOSS), and a Lunar Space Tug (LST).

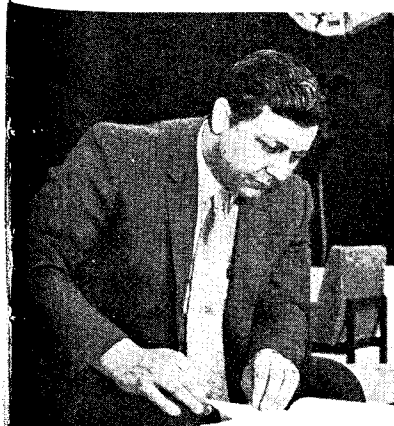
In a typical mission sequence the TLS will be used to transport personnel and cargo from an Earth-orbital base to the lunar space station. A LOSS would employ a conventional lunar transfer. HOSS, on the other hand, would use a powered lunar-swingby trajectory of the type shown in the next illustration (F-2). This maneuver substantially reduces the ΔV requirements for braking to the vicinity of the HOSS. After arriving at the lunar space station, the TLS transfers propellant to the LST and discharges its payload. The TLS then returns to Earth orbit. The LST transfers cargo and passengers to the lunar surface.

How do LOSS and HOSS compare in this strategy?

Operational Considerations: The most important reason for requiring a lunar space station in the future lunar program could be its function as a communications and control center for all lunar surface and orbital activities. The communications and control tasks would include—

1. Control of rendezvous and docking operations for the lunar shuttle vehicles.
2. Monitoring and control of the ascent and descent trajectories of an unmanned LST.
3. Navigation and control of unmanned lunar-surface vehicles.
4. Communications and navigational support for manned surface expeditions.
5. Control of unmanned remote-manipulator vehicles in the lunar vicinity. These vehicles require continuous communications and minimal transmission delay times for efficient operation. They would be used mainly for satellite maintenance and repair.
6. Command, control, and monitoring of all elements of the lunar program.

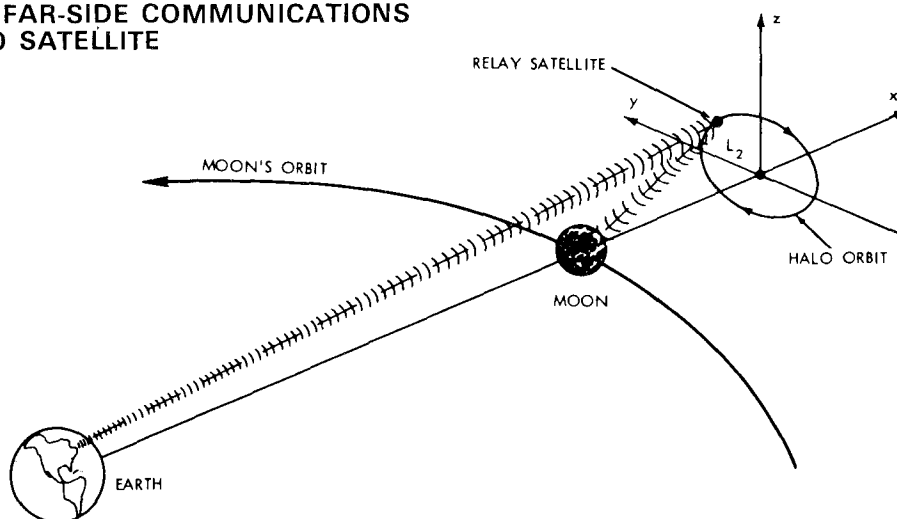
These tasks can be conducted very efficiently from a HOSS. It will give *continuous* communications coverage for all far-side lunar operations *directly*—without dependence on relay satellites. It likewise permits uninterrupted direct



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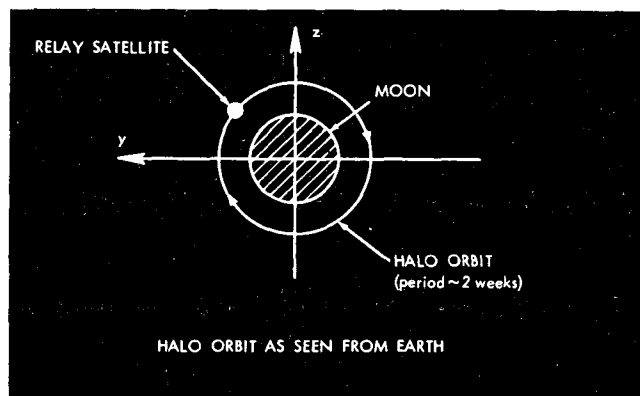
F-1 LUNAR FAR-SIDE COMMUNICATIONS WITH HALO SATELLITE

(Not to scale.)



MEAN DISTANCES

EARTH - MOON	: 384,400 km
MOON - L_2	: 64,500 km
HALO RADIUS	: 3,500 km



contact between the HOSS and Earth. Moreover, by placing a single relay satellite at the cislunar libration point, L_1 , the HOSS will always be able to communicate with almost every point on the Moon or in orbit about it. This type of communications and control network offers the additional advantage of being quasi-stationary with respect to the lunar surface. Finally, it should be noted that Earth stations already cover near-side lunar operations.

LOSS, in its 60-n. mi. polar lunar orbit, would be particularly ill-suited for the communications and control functions, for the following reasons:

1. A lunar surface base would not have any direct contact with the LOSS for periods as long as 11 days. Furthermore, the line-of-sight contact time would only be about 10 min per orbit even when the LOSS passes over the base site.

2. Continuous direct contact between the LOSS and the Earth would only be available for two 3-day periods each month. At other times, line-of-sight contact would be interrupted during every orbit.

3. The LOSS would be almost completely dependent on satellite and/or Earth relay links for

control of certain critical lunar operations (e.g., a surface rescue mission). Furthermore, two simultaneous relay links would usually be required and switchovers would occur every hour.

The continuous communications coverage of the lunar far-side from HOSS will be especially beneficial to a lunar astronomical observatory, which quite likely will be located on the far side of the Moon. In the 1967 Summer Study of Lunar Science and Exploration, the Astronomy Working Group recommended a near-equatorial far-side observatory site.⁵ This group also stated a preference for a crater with a diameter of about 100 km and a rim height greater than 1 km above a fairly flat crater floor. An area about 30 by 60 km free of cliffs, mountains, canyons, etc. is also desired for radio astronomy. It appears that these criteria nicely fit the crater Tsiolkovsky (F-3), shown on next page. This crater, also of much geological importance,⁶ could well be the most important post-Apollo lunar-exploration objective.

The lunar space station will be the principal logistics staging point for all lunar missions. There TLS payloads will be broken down into smaller

EARTH



F-3 The Tsiolkovsky crater becomes operational

540

500

460

ΔV (fps)

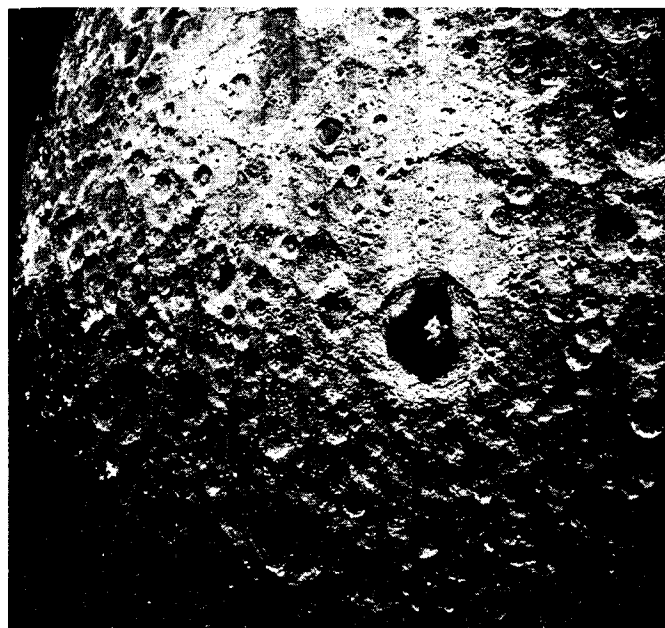
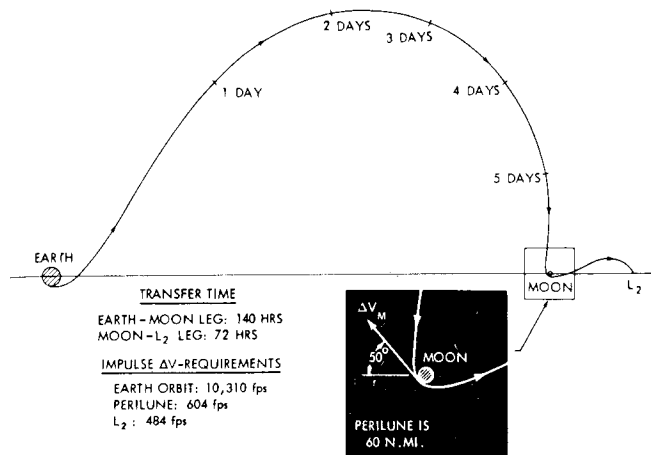
380

340

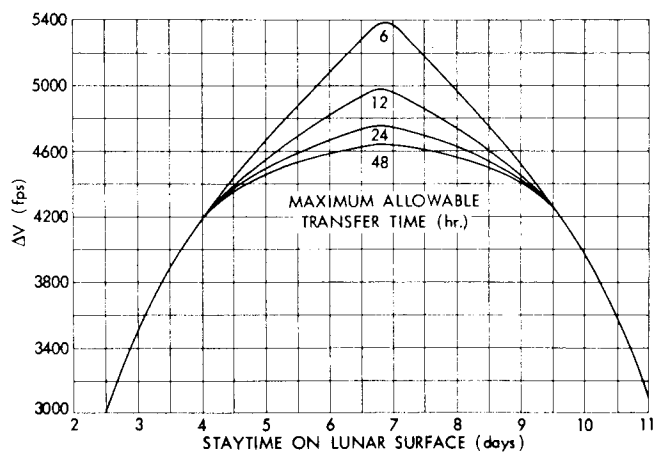
300

F-4 polar impact

F-2 THREE-IMPULSE TRANSFER (From 100-n. mi. Earth orbit to L_2 point.)

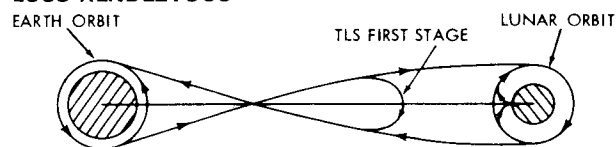


F-3 The southwestern area of the Moon's far side, showing Tsiolkovsky, the conspicuous dark-floored crater. This crater could become the most important site in post-Apollo lunar exploration and operations.



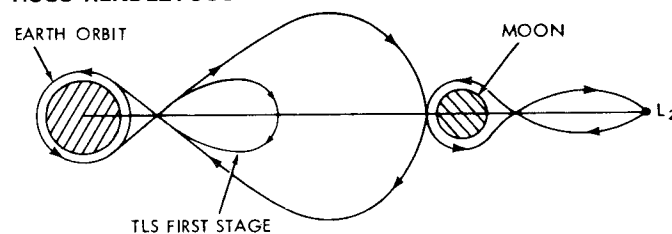
F-4 Plane-change ΔV penalty for a transfer between a 60-n. mi. polar lunar orbit and an equatorial landing site. (A near-optimal three-impulse transfer has been used.) After N. L. Faust.⁷

F-5 MISSION PROFILE FOR LUNAR SHUTTLE SYSTEM: LOSS RENDEZVOUS



1. TLS FIRST STAGE IS USED TO BOOST TLS INTO ELLIPTICAL EARTH ORBIT ($\Delta V \approx 7500$ fps). FIRST STAGE SEPARATES AND SECOND STAGE OF TLS PROVIDES REMAINDER OF THRUST REQUIRED FOR TRANSLUNAR INJECTION ($\Delta V \approx 2800$ fps).
2. TLS FIRST STAGE DEBOOSTS ITSELF INTO ORIGINAL EARTH PARKING ORBIT ($\Delta V \approx 10,300$ fps).
3. TLS SECOND STAGE BRAKES TO 60 N.M.I. LUNAR ORBIT ($\Delta V \approx 3000$ fps), DELIVERS PAYLOAD M TO LOSS, AND REFUELS LST THAT IS STATIONED AT LOSS.
4. LST DESCENDS TO LUNAR SURFACE ($\Delta V \approx 6600$ fps) AND DELIVERS PAYLOAD m . IT IS ASSUMED THAT $m = \beta M$, WHERE THE PAYLOAD FRACTION β HAS THE RANGE $0 \rightarrow 1$.
5. LST RETURNS TO LOSS ($\Delta V \approx 6200$ fps) AND TLS SECOND STAGE RETURNS TO EARTH ORBIT ($\Delta V \approx 13,300$ fps).

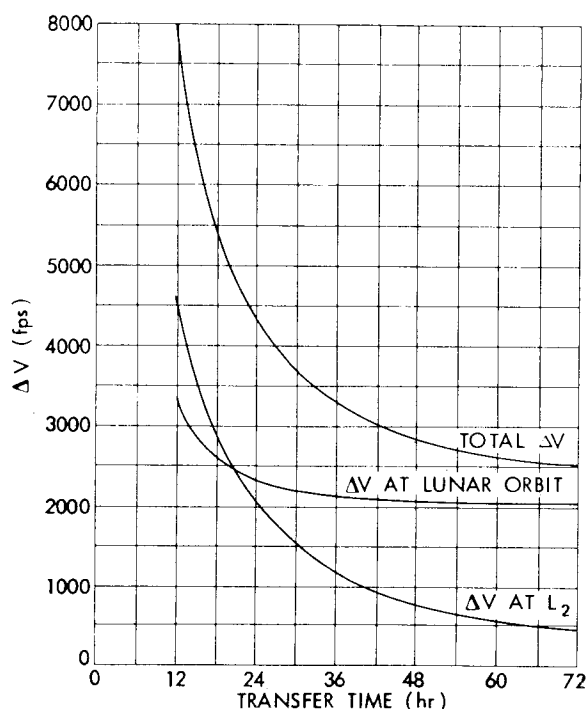
F-6 MISSION PROFILE FOR LUNAR SHUTTLE SYSTEM: HOSS RENDEZVOUS



1. TLS FIRST STAGE IS USED TO BOOST TLS INTO ELLIPTICAL EARTH ORBIT ($\Delta V \approx 6500$ fps). FIRST STAGE SEPARATES AND SECOND STAGE OF TLS PROVIDES REMAINDER OF THRUST REQUIRED FOR TRANSLUNAR INJECTION ($\Delta V \approx 3800$ fps).
2. TLS FIRST STAGE DEBOOSTS ITSELF INTO ORIGINAL EARTH PARKING ORBIT ($\Delta V \approx 10,300$ fps).
3. TLS SECOND STAGE BRAKES TO THE HOSS NEAR L_2 ($\Delta V \approx 1100$ fps), DELIVERS PAYLOAD M TO HOSS, AND REFUELS LST THAT IS STATIONED AT HOSS.
4. TWO-STAGE LST DEPARTS FROM HOSS AND BRAKES TO 60 N.M.I. LUNAR ORBIT ($\Delta V \approx 2550$ fps).
5. LST STAGES ARE SEPARATED IN LUNAR ORBIT AND FIRST STAGE RETURNS TO HOSS ($\Delta V \approx 2550$ fps).
6. LST SECOND STAGE DESCENDS TO LUNAR SURFACE ($\Delta V \approx 6600$ fps) AND DELIVERS PAYLOAD m . IT IS ASSUMED THAT $m = \beta M$, WHERE THE PAYLOAD FRACTION β HAS THE RANGE $0 \rightarrow 1$.
7. LST SECOND STAGE RETURNS TO HOSS ($\Delta V \approx 8750$ fps) AND TLS SECOND STAGE RETURNS TO EARTH ORBIT ($\Delta V \approx 11,400$ fps).

packages and then transported to the lunar surface by an LST. Most rendezvous, docking, and refueling operations will take place in the vicinity of the HOSS or LOSS. The lunar station will also serve as a hangar for lunar elements not in use, such as LSTs, remote-manipulator vehicles, relay satellites, and possibly even lunar-surface mobility aids. And it would provide extensive maintenance and repair services, and so greatly increase the reliability and useful life of these elements.

The halo orbit offers inherent operational advantages for logistics staging. For instance, the ΔV requirements for transfers between the halo orbit and the lunar surface are almost identical for any landing site, since plane changes can be made quite cheaply at the halo orbit. (The difference in ΔV cost is usually less than 200 fps.) It is also worth noting that, because of the quasi-stationary characteristic of the halo orbit with respect to the lunar surface, the launch window for transfers between the HOSS and the lunar surface is infinite.



F-7 ΔV requirement for a two-impulse transfer between the L_2 point and a 60-n. mi. equatorial lunar orbit. (A polar lunar orbit could require as much as 200-fps additional ΔV .)

On the other hand, with the logistics staging point in a 60-n. mi. polar lunar orbit, the nominal staytime for lunar surface sorties would probably be constrained to 14-day intervals. Otherwise, due to precession of the polar orbit, a plane change would be necessary when the LST returns to the LOSS. A graph (F-4) on page 61 shows the ΔV penalty for this plane change as a function of surface staytime.

The differences in launch-window flexibility for transfers between the lunar space station and an Earth parking orbit are not as clearcut as in the case of LST operations. Launch opportunities for economical TLS transfers are limited by certain varying geometrical factors. With a LOSS, these factors include Moon's position, nodal regression of the Earth parking orbit, and orientation of the LOSS orbit with respect to the Earth-Moon line. Transfers to the HOSS would not be subjected to the third constraint, but the transfer times would be somewhat longer than those required for the LOSS.

Selection of a low-altitude orbit for the LOSS had evidently been motivated by a desire to carry out an extensive program of orbital science (e.g., surface mapping, particles, and fields experiments) from the lunar space station. However, a recent study of possible scientific uses of a lunar orbital base concludes that "...scientifically, there is no strong justification for a lunar orbital base, and that such a base should not be established unless there are compelling non-scientific reasons for doing so...The orbital science, except for photography, can be performed as well, or better, from an unmanned, non-returning spacecraft."⁸ I agree with this conclusion, and therefore will not consider scientific uses of the LOSS or HOSS here.

Another oft-stated argument in favor of a LOSS has it an ideal base for a rescue LST. As can be seen from the graph F-4 on page 61, however, the plane change ΔV penalty can become rather high when a surface rescue mission is needed at an inopportune time. Notice that the ΔV cost is not very sensitive to the maximum allowable transfer time. For a rescue tug stationed at a HOSS, the tradeoffs are quite different, as the graph (F-7) just at left shows. From a ΔV standpoint, neither concept has a clear advantage for all rescue situations.

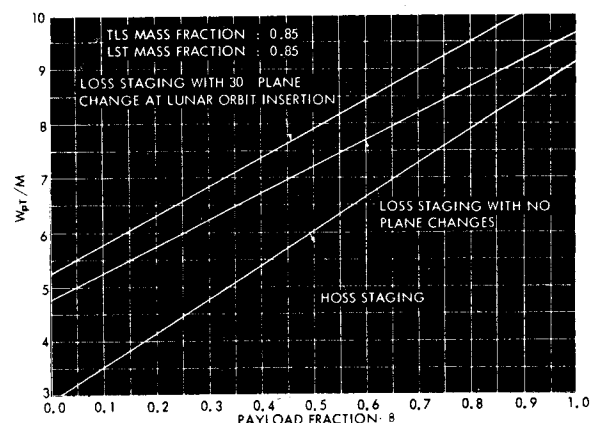
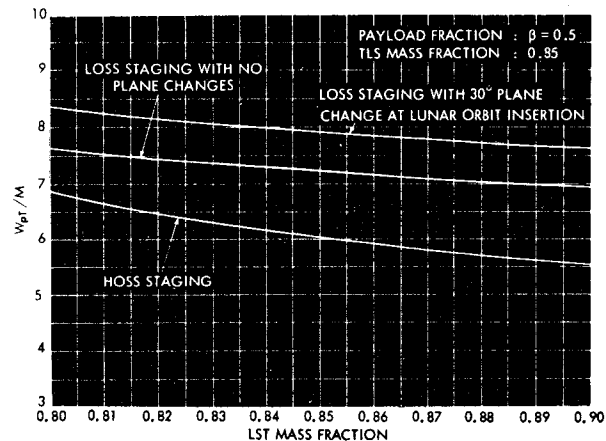
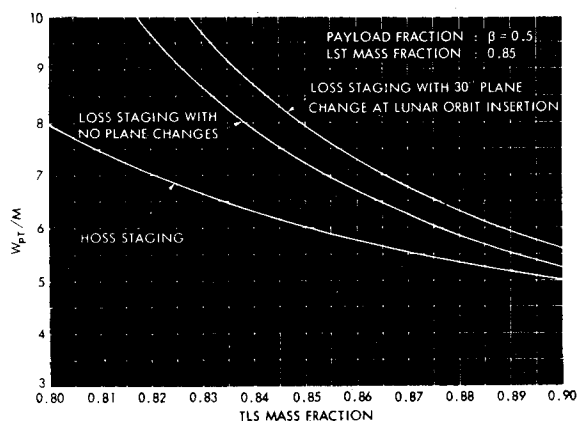
Finally, the station-keeping requirements of the two space-station concepts should be considered. Although the normal ΔV costs for the two concepts are almost equal (~ 400 fps per yr), the HOSS could remain in the vicinity of the L_2 point (with some occultation) at a cost of only 100 fps per yr. Without orbit control, the LOSS would impact with the lunar surface in about four months.

Briefly, it has been contended that a LOSS would "provide a highly stable, safe, and flexible operations base."¹ The factors just reviewed cast doubt on this claim.

Lunar-Shuttle Performance: The staging, and consequently the over-all performance, of the lunar shuttle system will differ importantly depending on the station used—HOSS or LOSS. For comparison, the performance for two typical mission modes, one using LOSS staging and the other HOSS staging,

F-8 LUNAR SHUTTLE PERFORMANCE

W_{PT} is the total propellant weight required by the TLS and the LST; M is the outbound payload.



will be given here. Two previous charts (F-5 and F-6) describe the pertinent mission profiles. Both cases assume that—

—All stages have a specific impulse of 444 sec (H_2/O_2 combination).

—Nominal module weights could be determined by assuming an outbound payload (M) of 90,000 lb.

—No payload is returned from the lunar surface or the lunar space station.

It should be also noted that the weight penalties for the crew and intelligence modules and the LST landing gear were not included in the payload or in computing the stage mass-fraction; but they were accounted for in the performance calculations.⁴

The performance for a particular mission mode can be evaluated by calculating the normalized propellant weight, W_{PT}/M (W_{PT} is the total propellant weight required by the TLS and the LST, and M is the outbound payload). Normalized propellant weights for the assumed mission modes are given in the graphs above.

Notice that the LOSS rendezvous mode is rather sensitive to plane changes at the lunar polar orbit. These results show significant performance gains with HOSS staging.

Conclusions and Recommendations: A halo-orbit space station could offer important operational and performance advantages compared to a lunar-orbit station in a second-

generation lunar program. Therefore, it is recommended that the present strategy for the lunar-program portion of the Manned Spaceflight Integrated Plan be reexamined. Comprehensive tradeoff should be initiated of several mission modes for reusable lunar shuttle systems using HOSS and LOSS rendezvous. These studies would provide the information needed to select unequivocally the most effective strategy.

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