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Paper Session II-C - Lunar Mission Architectures Compatible with Economic Launch Systems

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Need for a New Look at Architectures

Since the demise of the Space Exploration Initiative proposed by President Bush, the focus of U. S. civil space planning has been on completing the space station and accommodating the changes brought about by bringing the Russians into the program. The station program now seems to be on a steady course and flight hardware is being produced; first launch is scheduled for 1997. There is not much slack in NASA's budget, and expectations are that a gradual decline will occur over the next few years, leaving little room for significant new programs.

Recently much attention has been given to low-cost access to Earth orbit, particularly as single-stage-to-orbit (SSTO/RLV). A NASA program to demonstrate the technology for SSTO, the X-33, has been initiated. The RLV scenario visualizes private funding for development of an operational system, with investment to be recovered by some combination of shuttle service sales to NASA and launch sales to commercial customers. If this all works out, the U. S. will, early in the next century, have a commercially operated reusable launch system operating at much lower prices than today's systems. NASA's space transportation costs for servicing the space station could eventually drop to less than a billion dollars a year.

These scenarios seem to leave human exploration missions in limbo. The usual scheme, which begins with development of a 2 x Saturn V launch vehicle having large and indefinite development cost $20 billion or more, is clearly not in the cards. The present author argued three years ago that the big-launcher approach was not economic [1]. Somewhat later, a study by General Dynamics [2] made the same point. Last year [3], the present author described economic and policy approaches to lunar industrialization that look forward to economically beneficial uses of the Moon, focus on affordability, and argued that lunar architects should figure out how to work with low-cost small launchers because there is no other choice.

Before getting into the main subject there is one more introductory point. Some authors, in technical as well as popularized discussions of SSTO vehicles, have proposed that the SSTO could be refueled in orbit and flown to the Moon. This argument is made mainly about vertical landing SSTO configurations, and is even used as an argument for the vertical lander configuration. It is noted that the delta V to go from Earth orbit to the lunar surface and return to Earth orbit (or Earth) via aerobraking is essentially the same as the delta V to reach Earth orbit from the surface of the Earth. This is true enough, and the idea is technically possible. In fact, the turnaround maneuver is surely easier!

There are several reasons why this is not such a wonderful idea. First and foremost, achieving single-stage-to-orbit is near the limit of the engineering art. Additional requirements or compromises imposed by lunar travel should be avoided.

There is one requirement of great significance: The peak heating rates for return to Earth (either orbit or landing) from the Moon will be about twice those experienced during entry from orbit. Thermal protection system weight and design integrity are already an issue for SSTO and this does not need to be aggravated. The total heat load, at least for return to landing, will also be about double.

Other objections include: (2) Reasonable payload bay placement for the SSTO will make the vehicle extremely difficult to unload on the lunar surface. (3) The value of the SSTO vehicle is much greater than that of a lunar transporter; it is uneconomic to tie up such an expensive asset on lunar travel. (4) The payload-to-gross-weight ratio for an SSTO is about 1% compared to about 10% for an optimized lunar transporter; the cost of supplying propellant to Earth orbit would be high even at SSTO launch costs. (5) Required engine throttling for lunar landing is much deeper than for Earth landing. (6) Landing of the relatively long, slender SSTO configuration on an unprepared lunar site might risk tipover.

For these reasons I regard flying an SSTO to the Moon not an acceptable architectural solution and will not discuss it further in this paper.

Payload and Delivery Requirements

If one designs a lunar architecture for operation with SSTO or some other RLV configuration, one can be confident that the largest payloads to be delivered to the Moon will be no larger than those delivered to orbit by the RLV. It is conceivable that some payload assembly in Earth orbit might be desired to avoid assembly on the Moon but this is a vague argument. As discussed below, there are lunar transport configuration benefits for keeping the payload mass and size the same as the RLV capability.

The payload for RLV is not yet fixed. NASA has used 11.3 t. (25,000 lb) to the space station orbit as a working figure but what will arise during the current studies is of course not yet known. If launched due east from KSC to a 160 km orbit, the same vehicle (assuming it's an SSTO) could launch 18 to 23 t.

A useful reference point for early-period lunar payloads is the NASA FLO study (there are several references including [4]). FLO examined use of a space station lab module as habitat, with suitable modifications for operation on the lunar surface. The FLO hab as configured could not be launched by an RLV even if the mass delivery capability were available because FLO included external stores and equipment for lunar surface power and operations. These would not fit into the RLV payload bay volume. Roughly, the FLO mass was habitat 20 t., lunar surface electrical power and thermal control 7, airlock 2, and external crew aids 1. The crew transport system for FLO included an Earth return stage about 20 t. and a crew module about 8 t.

The extant literature does not conclusively show initial lunar base payloads that can't be delivered to Earth orbit, and on to the Moon, for payload mass capability of 20 t. and volume 4.5 m x 10 m. (or even 9 m. if the RLV payload ends up at exactly 30 feet). However, crew safety considerations argue decisively for mating the crew module to its Earth return stage for delivery to the Moon.

Therefore, for this short paper we adopt a lunar delivery payload of 28 to 30 t. and a payload volume of 4.5 x 10 meters. A special requirement derives from the crew configuration: the Earth return stage and crew module should be situated in the lunar delivery and landing system such that punch-out abort is possible. Also, adequate visibility of the lunar surface is needed for landing approach.

Operational Premises

In this short paper, we will highlight only a few significant operational premises.

(1) An assembly facility in Earth orbit will not be provided. Orbital operations also will not be done at the space station since launch performance is significantly degraded by the space station altitude and inclination requirements.

(2) No reliance will be placed on the RLV or its crew to support assembly operations.

(3) It is assumed that the RLV has the capability to deliver crew to and from the space station and that this capability is available to support lunar operations in an alternative orbit.

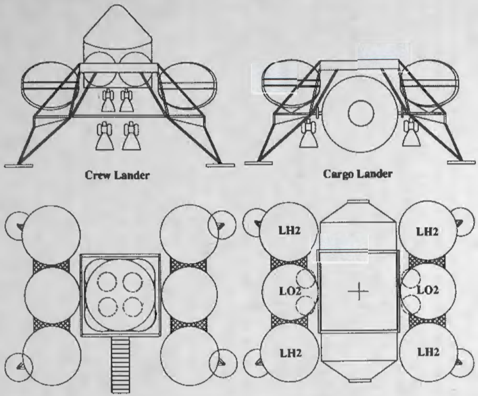
(4) Propellant transfer from a tanker brought to orbit in the payload bay of the RLV is permitted. The RLV is able to deliver hydrogen propellant in stage tanks or in a tanker but will not carry a crew on such flights.

(5) Debris protection will be built into any system which spends time in low Earth orbit between missions or for assembly operations. These systems will not be manned during such periods and therefore the amount of debris protection is determined by economics and not human safety. Similarly, orbit maintenance capability will be provided.

Concepts and Options

A lunar lander capable of delivering 30 t. will be too large and too massive to package in a single launch. Considering evolution to lunar oxygen (and possibly lunar hydrogen), an oxygen/hydrogen stage is preferred. A great many concepts have been published. One of the best concepts reviews, which directly addresses the issue of lunar surface operations, is [5]. This paper recommends a "bottom-loader" configuration because cargo can be easily unloaded. If the lander is made capable of handling the RLV payload mass and volume, one may be reasonably sure that this is adequate. The Figure illustrates such a concept, with a crew delivery variant which places descent engines under the center of mass of the lander for improved engine-out capability. Since this vehicle is much larger than the payload volume of the RLV, it must be assembled in Earth orbit. In an expendable mode, the propellant tanks can be launched loaded. In a reusable mode (with oxygen refueling on the Moon) the propellant tanks must be refueled from a tanker in Earth orbit. (The scenario for evolution to reusable, lunar oxygen operations was described in [1]). A translunar injection stage can be made up of the same types of components (tanks,

Crew and Cargo Landers, General Arrangements

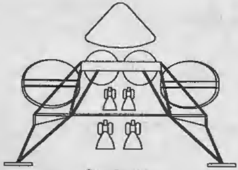


engines, structure, avionics) but with four oxygen tanks instead of two for launch mass limits.

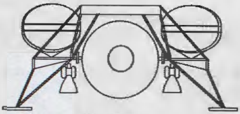
The depicted system is somewhere near the upper end of a range of reasonable initial concepts. If the return propulsion system uses cryogenic propellants, it can be smaller. The FLO-type habitat could be scaled down somewhat to be compatible with a smaller lander. While a crew of four was selected for the FLO mission, reference 2 presumes only 2, and 3 is of course also possible. One might select an integral descent/ascent cryogenic stage which could be used in descent-only mode for cargo delivery. This might provide a better matchup between smaller crew and larger cargo delivery requirements.

On-Orbit Assembly and Operations

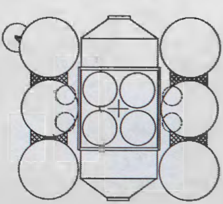
The on-orbit assembly concept involves deployable frame structure with engines attached as a first launch. This assembly would also include the avionics system and enough solar array to function as a free-flyer spacecraft during on-orbit loiter awaiting further assembly flights. The lunar lander would require three additional launches for propellant tanks and one or two for payload. The translunar injection (TLI) stage would require six to eight launches for propellant tanks. In a reusable mode about the same number of launches would be needed for tankers but the hardware would be reused.



Crew Lander



Cargo Lander



Assembly operations are assumed to employ a space tug for transfer of cargo from the RLV to the assembly site. This space tug has already been visualized as an element of RLV space station operations. The lunar lander deployable frame structure would include a small robot arm to place propellant tanks or tankers on the lander stage.

About 16 launches of an RLV are needed to stage a lunar mission, representing something like $400 million in launch cost, compared to a probable cost more than a billion for a large heavy lift launcher. The assembly operations depicted seem no more challenging than those planned for the space station program.

Conclusions

1. Current trends and planning for launch systems development dictate re-thinking lunar architectures to make them compatible with a modest capacity launch vehicle, but one capable of high flight rates and lower cost than the heavy lift alternative.

2. A plausible architecture is very similar to earlier concepts except a requirement for orbital assembly and operations.

3. The resulting architecture is indicated as less expensive to operate and much less expensive to put in place.

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