CEV Architectures – Cost Effective Transportation System to the Moon and Mars

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The Crew Exploration Vehicle (CEV) Program has become the future centerpiece for NASA's access to space for human spaceflight. The program is initially being built on the Orbital Spaceplane program to provide crew transportation capability to the International Space Station (ISS). However, the ISS is not the final human destination for NASA. On Jan 14, President Bush declared the goal of going to the Moon by 2020 and Mars sometime after 2030. However, cost of the program has become the central debate, and success may very well hinge on NASA not having to pay for the development of a new heavy lift vehicle. If NASA can use the already existing Evolved Expendable Launch Vehicle (EELV) system for Lunar and Mars missions, it will not only make them affordable, but also ensure commonality with commercial and military lift requirements. Having the military and NASA using both versions of the EELV will result in lower launch costs for the entire nation. This paper will analyze different CEV & EELV architectures to transport humans to the entire Near Earth Environment (including lunar orbit and any of the Earth – Moon Lagrangian Points). While the advantage of lunar orbit is obvious, it is just as important to reach a Lagrangian point since it would be the key staging point for a cost effective Mars transportation system.
To use the EELV for a moon or Lagrangian mission will probably require 2-boosters orbital rendezvous. But what is the best orbit to rendezvous at before setting off for the Moon or Mars? What is the effect of using hydrogen and oxygen propellants mined on the moon? Can a single EELV launch both a landing craft in addition to an orbital transfer vehicle if lunar oxygen is used? This paper will answer some of these questions by looking at the mass returned to earth for the different architectures. The results show that given certain size considerations, EELV and CEV together can provide a cost effective way for human exploration of the entire Near Earth System and destinations beyond.

Nomenclature

GEO	= Geostationary Earth Orbit
EELV	= Evolved Expendable Launch Vehicle
RLV	= Reusable Launch Vehicle
CEV	= Crew Exploration Vehicle
CRV	= Crew Return Vehicle
CTV	= Crew Transport Vehicle
OSP	= Orbital Space Plane
ISS	= International Space Station
Near Earth Environment	= Region within the Earth's Sphere of Influence
Block A	= Crew Transport Vehicle to the International Space Station
Block B OSP	= Crew Transport Vehicle to Near Earth Environment

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OTV = Orbital Transfer Vehicle

I. Introduction

The objective of this paper is to demonstrate that a moderately sized Crew Exploration Vehicle (CEV) launched by either the Delta IV or Atlas V Evolved Expendable Launch Vehicle is a cost effective system for manned travel within the near Earth environment and a stepping stone for missions to Mars. Near Earth environment is defined as anything in the Earth / Moon sphere of influence including lunar orbit and the Earth / Moon Lagrangian Points. The analysis in this paper is threefold. First, it defines mass requirements for CEV/EELV missions to the International Space Station (ISS). Second, it develops low-cost transportation architectures to the lunar surface. This lunar transportation analysis is the most in-depth because it represents the highest Delta V requirements for the Near Earth Environment. Finally, the paper outlines the propulsion requirements for using the CEV for transportation to one of the Earth / Moon Lagrangian points. The Lagrangian point represents the most logical first stage of a three stage process for Mars missions. The first stage is from Earth to a Lagrangian Point. The second stage is from the Earth's Lagrangian Point to a Mars Lagrangian Point. The third stage is from the Mars Lagrangian Point to Mars. A detailed analysis of the second and third stages will be presented in future papers. If the long term goal of NASA is a cost effective transportation system to the ISS, the Moon, and Mars, the CEV / EELV system has many developmental and long-term benefits. Not only will these benefits spell success for the nation's goal to explore the Moon and Mars, but it could also be the key to significantly lower launch cost for the nation's commercial and military communities

II. Assumptions for the Transportation System

Because the total cost of the system is the driving requirement for an acceptable space transportation system, launch vehicle development costs need to be minimized. Also, launch costs are directly related to economies of scale. The best hope for low recurring launch costs are if NASA leverages launch systems used by the military and commercial sectors. Our analysis is based on the following EELV assumptions:

A. NASA Should Not Develop an Ultra Heavy Lift Vehicle

With NASA's proposed budget receiving real growth for only the first three of the next 15 years, it will not allow NASA to develop another ultra heavy lift vehicle. The EELV launch vehicles are rapidly becoming the standard for the United States commercial and military space lift. Both brands of EELV leverage heritage proven technology to produce the most reliable, economical, and safe launch vehicles available. As a result EELV is the most effective U.S. launch system for getting manned payloads to orbit for the near future. By using EELV instead of sinking billions into development of a new launch system, NASA can take advantage of the reliability and low cost of a proven national asset before humans are ever put in harms way. This will not only help NASA, but will also help drive down the cost for commercial and military launches. A 70% reduction in launch costs could be realized if EELV has block buys over 30 [5]. Not only would economies of scale be realized in the American launch industry for the first time in many years, but the demand would enable a healthy launch market to maintain both EELV contractors ensuring NASA, the DoD, and commercial users assured access to space.

Developmental costs of the CEV, lunar lander, and lunar base, are burden enough to drain the NASA coffers in the next decades. Using the EELV for CEV missions to ISS and the moon will reduce astronaut risk while avoiding launch vehicle development costs. The result is increased likelihood of program success, even in the face of fluctuating budgets and a risk-averse nation. As this paper will show, the EELV has the ability to launch missions to the moon and ultimately on to Mars!

B. EELV Can be Man-Rated without Significant Cost or Loss of Lift Capacity

To date, two thirds of all manned launch vehicles were derived from existing unmanned expendable launch vehicles. Soyuz, Redstone, Atlas, Titan, and Long March are all unmanned launch vehicles successfully converted to human transportation. This historical fact provides much credibility that EELV can be effectively manned rated and bodes well for the likely safety record of such a launch system whose flaws are worked out well in advance of human crewmembers.

C. Evolved Capability of the CEV Architecture

A near term CEV needs to be developed for continuous transportation to and from the ISS, defined in this paper as Block A CEV. For the most efficient use of development funds, the design of the CEV should also take into account the use of the ISS Block A CEV or a modification of it, for manned travel to the Moon and Lagrangian Points, defined herein as the Block B CEV. As can be seen in Appendix B, the energy (delta V) required for a lunar mission is sufficient for a mission to a Lagrangian Point.

D. CEV Will Use Airbraking for Reentry

By using airbraking for reentry, the propulsion energy (delta V) requirements for both the Block A and Block B CEVs, is lowered by roughly three km/s for Earth atmospheric reentry. Minimizing this return leg propellant requirement drastically reduces overall CEV propellant requirements and increases the number of crew members the CEV can support.

III. A Premise Built from these Assumptions

A very large recurring savings can be realized if the CEV launch mass is held to a moderate size. This will enable CEV missions to ISS (defined hence as Block A) to be launch on an EELV Medium. If we base our estimates of CEV mass on the original ISS Crew Return Vehicle (CRV) a lightweight Block A CEV would have a mass of approximately 9,000 kg. (REF 1). A medium EELV can lift approximately 8, 500 kg to a 500 km, 51.6° inclined orbit.

A second reference is the current ISS transportation system, the Russian Soyuz space capsule. With a mass of 7,100 kg it was originally designed for lunar missions and is the most used transportation system to space stations in human history. It is launched on the Soyuz launch vehicle which has less capability than the EELV medium (7,000 to 8,500 kg (Ref 2 and 3)). Therefore, it is reasonable to assume that the Block A CEV can be designed in the 7,500 – 8,500 kg range and still carry three or four crewmembers.

If the CEV is held to a moderate size it allows for a "Block B" CEV to perform Moon and Mars stage 1 missions. The Block B CEV will be launched on an EELV Heavy, and will probably be augmented by a separately launched service module or external tank launched on another EELV booster. The following section provides the first order analysis. Its objective is to find the maximum mass that can be lifted to lunar orbit/Lagrangian Point by a combination of Medium and Heavy EELVs. Since Block B will have many of the systems as Block A, we will require the architecture to be able to transport at least an 8,000 kg Block B CEV (mid-range for Block A).

IV. Analysis of Potential Near Earth CEV Systems

A. Definitions

Two very basic Block B CEV configurations were chosen for analysis. The first option for a Block B CEV configuration is a major redesign the CEV all the propulsion and support subsystems needed for lunar transfer incorporated into the CEV. Since the CEV will reenter the earth at high velocities, minimizing CEV surface area will be critical for an efficient thermal protection and structure system. To reduce exposed surface area of the CEV during reentry it may prove beneficial to discard propellant tanks (now nearly empty) prior to reentry. By ejecting propellant tanks Block B CEV configuration will reuse expensive systems while less expensive systems are jettisoned prior to earth re-entry much as the Shuttle's External Tank is discarded following launch. The major disadvantage of this Block B CEV design option is that it differs significantly from the ISS (Block A) CEV.

A second candidate for a Block B System is to use a CEV combined with a service module/Orbital Transfer Vehicle (OTV). Attached to the CEV would be an expendable service module similar to the Apollo Service Module. This approach requires fewer design changes from the Block A CEV than the previous mentioned configuration. An attached service module can be much closer in form and function to existing upper stages which should result in lower development cost and perhaps higher performance. The system does have the disadvantage of using expendable service modules that would incur additional costs on every mission. Since this is the more conservative approach concerning technology risk, this is the configuration selected in this paper for analysis.

Integral to the CEV is the system that transports the astronauts to and from lunar surface and orbit (the lunar lander). Three conditions could dramatically increase the efficiency of the lunar lander over the one used in the Apollo Program. The first condition is the potential use of lunar water ice for lunar propellant production. A reusable lunar lander using lunar propellant could dramatically change the costs of a long term lunar program. The second condition is that the technology for fluid transfer in space has advanced. As a result, using the lunar lander to refuel the CEV for the return trip has great potential. Finally, unmanned rendezvous technology has considerably advance in the last 40 years and leaving an astronaut in a lunar orbiter is probably unnecessary and unwarranted for long stays on the surface. As a result, the Lander can serve as a carrier vehicle to take the CEV from lunar orbit to the surface. There are pro's and con's for the lunar lander having a cabin; however, this paper has focused it's analysis on the CEV and will not do a trade analysis of the lunar lander system.

B. CEV Requirements

The ISS, lunar orbit, and ultimately the Lagrangian points (for Mars missions) are the highest priority destinations for the CEV. Therefore, the CEV will need to the support the astronauts for total travel duration on the order of 6-7 days (~21 for hohmann to parabolic). Also, the CEV might be stationed at the destination (unmanned) for approximately 6 months before return. This needs to be factored-in during analysis of different propellants. Obviously this brings challenges to the use of cryogenic fuels but this is another area where significant progress has been made since the Apollo days.

C. Propellant Selection

Because the lunar transportation mission has the highest Delta V requirements (See Appendix B), that mission is analyzed first. Both non-cryogenic and cryogenic propellants were considered. Non-cryogenic propellants are more easily stored in space which is advantageous when the return trip might be 3-6 months later. We choose H_2N_4 and N_2O_4 in our analysis to represent this category. However, since launch mass is critical, using higher performance cryogenic (H_2 and O_2) propellants might be the critical enabler in a cost effective EELV/CEV transportation system. The use of Lunar H_2 and O_2 could more than half the required launch mass of a lunar bound CEV. In addition, research and development of cryogenic upper stage technologies including Zero Boil-Off (ZBO) storage systems has advanced tremendously in the last 40 years (note 4).

D. Architecture Analysis

For the Block B CEV's, the design to get to lunar orbit was the focus. The delta V required to enter and leave lunar orbit is more than that required to reach any of the Lagrangian points (possible launch and recovery points for a Mars mission). Appendix A lists the various architectures and how they compare in terms of CEV mass that is returned to earth. Appendix A includes the spreadsheet for calculation of CEV mass returned. CEV returned mass directly affects the size of subsystems, payload, and ultimately the number of astronauts fairied. As mentioned before the threshold for a satisfactory architecture performance will be the ability to transport at least an 8,000 kg Block B CEV.

The trade-space for these architectures is propellant selection, rendezvous point, insertion point and insertion point for EELV. Configurations A through D do not rely on lunar propellants and could be used long-term if lunar propellant production is not pursued, or during the early phases of a lunar station until lunar production of propellant begins. Configurations E through H all rely on lunar propellants provided by a separate vehicle which will land on the moon, and return to the CEV with a supply of propellant for use by the CEV for the return trip to earth.

E. Results

As shown in Table 1 (below) and in Appendix A, five of the eight architectures considered meet the criteria of being able to provide round-trip transportation of at least an 8,000 kg CEV (B, C, D, G, and H). All eight architectures are presented to understand the lessons from each.

Name	Description	2nd EELV	Lunar propel.	CEV mass (kg)	Analysis Summary
A	EELV H launches the CEV into trans-lunar injection (TLI) and must rendezvous with the Service Module that is already on the figure 8 orbit. Challenge is the CEV would need life support for the duration of the figure 8 in case it doesn't meet up with the Service Module (SM). Fortunately, the performance is bad so we can discard this architecture also.	Y	N	5200	Bad
B	EELV M+ launches non-cryogenic propellant service module to LEO. Next EELV H launches CEV for rend. Combined stack does round trip to lunar orbit without lunar propellant.	Y	N	7400	Good – simple propulsion design, but smaller CEV
C	EELV M+ launches cryogenic propellant service module to LEO. Next EELV H launches CEV for rend. Combined stack does round trip to lunar orbit without lunar propellant	Y	N	9900	Good – probably 1st phase before lunar prop produced
D	EELV H launches cryogenic propel service module to LEO. Next, EELV H launches CEV + lunar lander to rend. with SM. Combined stack does round trip to lunar orbit without lunar propellant	Y	N	12600	Good – Uses 2 EELV H – potential to transport lander
E	EELV H launches the CEV and Service Module into Lunar orbit. The EELV upper stage performs both the TLI and the lunar orbit insertion (LOI). The service module performs trans-earth injection (TEI), and earth orbit insertion (EOI) to leave lunar orbit and enter LEO at earth.	N	Y	4700	Bad for CEV, but cheap way to get Lunar Lander in position.
F	EELV Heavy (H) launches the CEV and service module into TLI. The service module is fueled with either lunar produced propellant or The service module performs the LOI, TEI, and EOI burns.	N	Y	5600	Bad – Option shows multiple negatives to TLI rendezvous
G	EELV H launches combined CEV and service module to LEO. Service module performs TLI and LOI. In lunar orbit, service module refuels with lunar produced propellant or tank from earth.	N	Y	8400	Good – especially without needing an additional EELV launch

H	EELV Medium Plus (M+) launches the service module into 500km LEO. Soon after EELV H launches CEV and lunar lander which rendezvous with the service module. Combined CEV/SM performs round-trip to lunar orbit and back using lunar propellant or another tank in lunar orbit.	Y	Y	11000	Good – higher capability and only requires EELV M+ for second launch.

Table 1. Various CEV/EELV architectures considered.

Architectures A - D do not use lunar propellant and will be discussed first. Architecture A uses two EELV heavies to launch the CEV / service module into trans-lunar orbit. However, it results in low performance (7,300 kg CEV) and thus all other architectures rendezvous in LEO. Architecture B uses storable propellant and two EELV Heavy launches. It is able to transport an 8,500 kg CEV and makes a good candidate if lunar propellant production is never pursued and storing cryogenics in orbit is deemed too risky. Architecture C uses H_2 and O_2 as propellant for the service module. An immediate savings from the cryogenic propellants can be seen in the fact that the additional launch is only an EELV Medium Plus (4 solid strap-ons) yet it has better performance than Architecture B that uses an EELV Heavy for the additional launch. Architecture C has the lowest launch costs of the alternatives that do not use lunar propellant. Architecture D uses two EELV Heavy launches with a cryogenic service module. This alternative has the highest performance of these four architectures and allows CEV mass to exceed 12,000 kg and still work.

Architectures E through H use lunar propellant to refuel the CEV / service module for the return trip. Architecture E may be the lowest-cost since it uses the EELV upper stage as the service module (though some upper stage upgrades are required). This would save development and acquisition of a service module; however at 4,300 kg the performance was significantly underneath the threshold of a useful CEV mass and therefore rejected. Architecture F uses the EELV to launch into Trans-lunar Injection and a small service module for lunar orbit insertion, trans-earth injection, and the portion of earth orbit insertion not provided during aero-capture. An interesting note for this alternative is the return trip requires more Delta V from the service module so it would be sized from that part of the trip. Both Architecture E and F have performance significantly under 8,000 kg and won’t be considered further. Architecture G uses only one EELV Heavy to launch the CEV and service module into low earth orbit. Significantly, this architecture shows by using cryogenic, lunar propellant, NASA could transport an 8,500 kg CEV to and from lunar orbit using only one EELV. This architecture has the lowest launch costs of any alternative. Architecture H uses an EELV Heavy and Medium Plus (4 meter fairing and 2 solid strap-ons) to launch the CEV and service module using lunar propellant for the return trip. As expected, this can transport a heavier CEV (12,500 kg) than Architectures E – G but requires an additional EELV launch to perform this.

Since Architectures E through H rely on lunar propellant, a quick analysis showed that an EELV Medium Plus (4 meter fairing and 2 solid strap-ons) could place 4,000 kg of propellant in lunar orbit (Appendix A). This amount of propellant is enough to refuel any of the CEV Architectures for a return trip to earth. Finally, a quick analysis showed a refuelable lunar lander with capacity for an 8,000 kg CEV would have a mass of approximately 9,100 kg. This could be placed into lunar orbit with a single EELV Heavy with an extra upper stage.

Finally, any of these CEV architectures could be used to transport astronauts to any of the Earth / Moon Lagrangian Points. Architectures A – D could be used as – is because the delta V to and from lunar orbit is greater than that to the Lagrangian Points. For example the trip to L1 is 3.8 km/s outbound and 0.8 km/s return vs. 4.1 km/s outbound and 1.1 km/s return to lunar orbit (reference 6, page 7). Also if lunar propellant production is pursued during the Moon missions, Architecture E – H could be using during the Mars mission to ferry astronauts to the Mars ship at one of the Lagrangian points. In this scenario the lunar lander would bring propellant for the CEV at the Lagrangian point.

V The Future

A. A Vision for NASA's Future Manned Lunar Mission

With the development of a lunar base, missions to Mars, and other large NASA missions, future manned lunar missions require a relatively low cost transportation system for the lunar post. Using Architecture C for early missions and Architecture G (once lunar propellant is available) is probably the most cost effective system available. It is generally accepted that most lunar equipment will be transported on missions separate from human missions. One possibility is to use a Heavy EELV with electric upper stage to get to lunar orbit and use the lunar fueled, lunar lander to rendezvous in lunar orbit and transport the equipment to the lunar base. A lunar base could be semi-permanent or permanent. A rotation scenario for a permanent lunar base could use 3 CEV missions every 120 days to swap out 3-4 person crews. A semi-permanent lunar base could send single or back-to-back missions for 3-6 months. This may be preferred if the lunar base is at a high latitude for utilization of potential lunar H_20. If the base is at a high enough latitude, the base will have little or no sunlight during its "winter". Therefore it would probably be occupied a maximum of 6 months out of the year.

B. A Vision for NASA's Future Manned Mars Mission

The Block B CEV has the capability to shuttle astronauts to an Earth / Moon Lagrangian point as the first stage of a three stage Mars mission. The second stage consists of the transport vehicle traveling from the Earth Lagrangian Point to the Mars Lagrangian Point. The third stage is the transport vehicle from the Mars Lagrangian Point to the surface of Mars. The power in this concept is rooted in delta V and time. The trip to Mars will take a considerable amount of time (3 -6 months). This will require life support systems, a solar storm shelter, habitable volume, etc much like a mini-space station. Trying to bring this fairly massive spacecraft deep into Earth and Mar's gravity well is incredibly in-efficient. It requires much less energy and propellant to transport small capsules like the CEV in and out of planetary gravity wells where the trip time is measured in days and the mini-station to go between planets where trip time is long.

Two leading candidates for low Delta V transportation methods between an Earth Lagrangian Point and a Mars Lagrangian Point are Cyclical Mars Ships or an Earth - Mars Lagrangian Shuttle. The Cyclical Mars ships would be mini-space stations orbiting the Sun with a periapsis near earth's orbit and apoapsis near Mar's orbit. For timing purposes this would probably require two ships. This concept is defined in detail in Pioneering the Space Frontier p. 136-8. The concept of the Earth - Mars Lagrangian Shuttle is for a space craft between an Earth Lagrangian Point and a Mars Lagrangian Point. (See Fig XXXXX) The Lagrangian Shuttle has many advantages to include the need for only one ship and more flexible mission timing. An analysis of various methods of transport between the Lagrangian Points will be addressed in a future paper.

VI. Conclusions

By keeping the CEV in a total gross weight range of 7,500 – 8,500 kg, the ISS CEV could be launched on a Medium EELV and a Near Earth Environment CEV could be launched on a Heavy EELV. The CEV design should allow for different blocks of vehicles (one for a larger crew to ISS, and one for a smaller crew to lunar orbit). Development of in situ lunar oxygen production would provide a much more efficient transportation system. Even without lunar propellant production, a cost-effective lunar post transportation system is available with current launch systems and a future CEV. These concepts use current launch systems. Therefore, much of the development costs are negated. Much more importantly, all three customer groups (civil, commercial, and military) use a common launch system. If NASA launches three Heavy EELV per year along with the military and commercial requirements for Medium and Heavy EELV, you have just built economies of a scale to make the EELV family a low cost system for all three customers (win /win/win).

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Appendix A

Name	Description	2nd EELV	Lunar propel.	CEV mass (kg)	Analysis Summary
A	EELV H launches the CEV into trans-lunar injection (TLI) and must rendezvous with the Service Module that is already on the figure 8 orbit. Challenge is the CEV would need life support for the duration of the figure 8 in case it doesn't meet up with the Service Module (SM). Fortunately, the performance is bad so we can discard this architecture also.	Y	N	5200	Bad
B	EELV M+ launches non-cryogenic propellant service module to LEO. Next EELV H launches CEV for rend. Combined stack does round trip to lunar orbit without lunar propellant.	Y	N	7400	Good – simple propulsion design, but smaller CEV
C	EELV M+ launches cryogenic propellant service module to LEO. Next EELV H launches CEV for rend. Combined stack does round trip to lunar orbit without lunar propellant	Y	N	9900	Good – probably 1st phase before lunar prop produced
D	EELV H launches cryogenic propel service module to LEO. Next, EELV H launches CEV + lunar lander to rend. with SM. Combined stack does round trip to lunar orbit without lunar propellant	Y	N	12600	Good – Uses 2 EELV H – potential to transport lander
E	EELV H launches the CEV and Service Module into Lunar orbit. The EELV upper stage performs both the TLI and the lunar orbit insertion (LOI). The service module performs trans-earth injection (TEI), and earth orbit insertion (EOI) to leave lunar orbit and enter LEO at earth.	N	Y	4700	Bad for CEV, but cheap way to get Lunar Lander in position.
F	EELV Heavy (H) launches the CEV and service module into TLI. The service module is fueled with either lunar produced propellant or The service module performs the LOI, TEI, and EOI burns.	N	Y	5600	Bad – Option shows multiple negatives to TLI rendezvous
G	EELV H launches combined CEV and service module to LEO. Service module performs TLI and LOI. In lunar orbit, service module refuels with lunar produced propellant or tank from earth.	N	Y	8400	Good – especially without needing an additional EELV launch
H	EELV Medium Plus (M+) launches the service module into 500km LEO. Soon after EELV H launches CEV and lunar lander which rendezvous with the service module. Combined CEV/SM performs round-trip to lunar orbit and back using lunar propellant or another tank in lunar orbit.	Y	Y	11000	Good – higher capability and only requires EELV M+ for second launch.

Insert Tab #1 from spreadsheet

Appendix B: Reference Numbers (Table 2)

Assumptions

1. It would be cheaper to man rate an EELV w/o SRM's, thus CEV Block A uses EELV Medium
2. LEM would be launched seperately and rendez. in lunar orbit
3. LEO for these calculations is 500 KM, 28.5 deg circular, or 51.6deg for ISS

EELV capability (kg's)

	Low Earth Orbit		Translunar Inj	Lunar Orbit
	28.5 deg	51.6 deg		
EELV Medium capability = (Payload Planners Guide page)	8,900 "2 - 13"	8,450 "2-13"	Not App.	Not App.
EELV Medium Plus (4,2) = (Payload Planners Guide page)	12,500 "2-20"	Not App.	Not App.	Not App.
EELV Medium Plus (5,4) = (Payload Planners Guide page)	14,500 "2 -34"	Not App.	5,000 "2-33"	Not App.
EELV Heavy = (Payload Planners Guide page)	25,500 "2-41"	Not App.	8,300 " 2 - 40"	5,300 "2-40"

Delta V's (m/s) (from LEO)

		Time (days)
Moon		
Delta V for Translunar Insertion (TLI) (note 1) =	3200	3
Delta V required for lunar orbit insertion(1) =	900	
Delta V for Transearth Insertion (TEI) (1) =	910	
Delta V for TEO (with aerobrake) (1) =	200	3
L-2 (Earth-Moon)		
Delta V to L-2 (2) =	3400	
Delta V from L-2 (with aero) (3) =	600	
L-1 (Earth - Moon)		
Delta V to L-1 from LEO (5) =	3700	
Delta V from L-2 (with aero) (5) =	770	
L-1 (Sun-Earth)		
Delta V to L-1 (2) =	3200	
Delta V from L-1 (with aero) (3) =	400	
GEO		
Delta V to GEO from 250km,28.5=	3.9	
Earth - Mars Cycling Spaceships ?? (4)		

1. Taken from Woodcock (p 119): My assumptions:
2. Taken from Keaton(p152): My assumptions
3. Taken from Keaton(p148&151): I added 100m/s for aerobraking to his #
4. OSP could transport to the earth mars cycling spaceships in Poineering the Space Frontie (136-8)
5. Siegfried (page 7)