Analysis of Shroud Options in Support of the Human Exploration of Mars

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Abstract—In support of the Mars Design Reference Architecture (DRA) 5.0, the NASA study team analyzed several shroud options for use on the Ares V launch vehicle.[1,2] These shroud options included conventional "large encapsulation" shrouds with outer diameters ranging from 8.4 to 12.9 meters (m) and overall lengths of 22.0 to 54.3 meters, along with a "nosecone-only" shroud option used for Mars transfer vehicle component delivery. Also examined was a "multi-use" aerodynamic encapsulation shroud used for launch, Mars aerocapture, and entry, descent, and landing of the cargo and habitat landers. All conventional shroud options assessed for use on the Mars launch vehicles were the standard biconic design derived from the reference shroud utilized in the Constellation Program's lunar campaign. It is the purpose of this paper to discuss the technical details of each of these shroud options including material properties, structural mass, etc., while also discussing both the volume and mass of the various space transportation and surface system payload elements required to support a "minimum launch" Mars mission strategy, as well as the synergy, potential differences and upgrade paths that may be required between the Lunar and Mars mission shrouds.

[2] IEEEAC paper #1169, Version 2, Updated November 4, 2009

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1. INTRODUCTION

The purpose of this paper is to discuss the conceptual designs of launch vehicle payload shroud options for a future human mission to Mars. Additional information is provided on the multi-use shroud concept that details the technical challenges and the additional analysis performed to date. These shroud options are envisioned for use on the Ares V heavy-lift launch vehicle, which is currently in the requirements definition phase of NASA's Constellation Program. These shroud options were defined in support of the recently released Mars DRA 5.0 study. [1] A more comprehensive description of the shroud options dimensions, materials, structural configuration, and functionality will be discussed, as well as current thoughts for synergy among shroud options for the Lunar and Mars missions.

2. OVERVIEW OF MARS MISSION

Surface System Payload Element Overview

For the Mars DRA 5.0, the surface mission scenario selected is known as the "commuter" architecture. It consists of centrally located, monolithic habitat, two small pressurized rovers, and two unpressurized rovers (roughly equivalent to the Apollo Program lunar rover vehicle (LRV). This combination of habitation and surface mobility capability would allow for landing sites in relatively flat and safe locations, while still providing the range to reach nearby regions of greater geologic diversity.

Power for these systems would be supplied by a nuclear power plant that was previously deployed with the descent/ascent vehicle (DAV) and used to make a portion of the ascent propellant. Surface transportation would be a significant feature of the exploration strategy that would be used in this scenario, but this travel would be constrained by the capability of the small pressurized rover. The rovers would have a crew of two, a 100 km total range before resupply and one- to two-week duration. Crew accommodations would be minimal, but these rovers will be able to place the crew in close proximity to features of interest to view from inside the rover or within easy walking distance. Some part of the crew would remain at the central habitat.

A fission surface power system (FSPS) landed by the cargo lander supplies electrical power to the cargo and habitat lander systems. An "in-situ" resource utilization (ISRU) plant supplies liquid oxygen (LOX) propellant for the Mars ascent vehicle (MAV) by converting Martian atmosphere into oxygen for use as propellants and life support and water and buffer gases for use in the surface habitats and mobility systems.

The volumes and masses of each of these surface elements were estimated [1] using parametric scaling relationships and sized for the DRA 5.0 mission architecture requirements. The Ares V shroud concepts were designed to accommodate a wide range of those potential designs.

Space Transportation Requirements

Mars DRA 5.0, shown in figure 1, comprises a 7-launch human Mars mission campaign [2]. It requires a cargo heavy lift vehicle (HLV) capable of delivering approximately 110-140 metric tons (mT) of net usable payload to a low Earth orbit (LEO) of approximately 220 n. mi. (407 km) and a large payload shroud to accommodate the basic vehicle and mission payload elements. DRA 5.0 features a split cargo/piloted mission scenario. Two cargo flights are used to pre-deploy a cargo lander, which includes the DAV, to the surface, and a habitat lander into Mars orbit where it remains until the arrival of the crew on the next

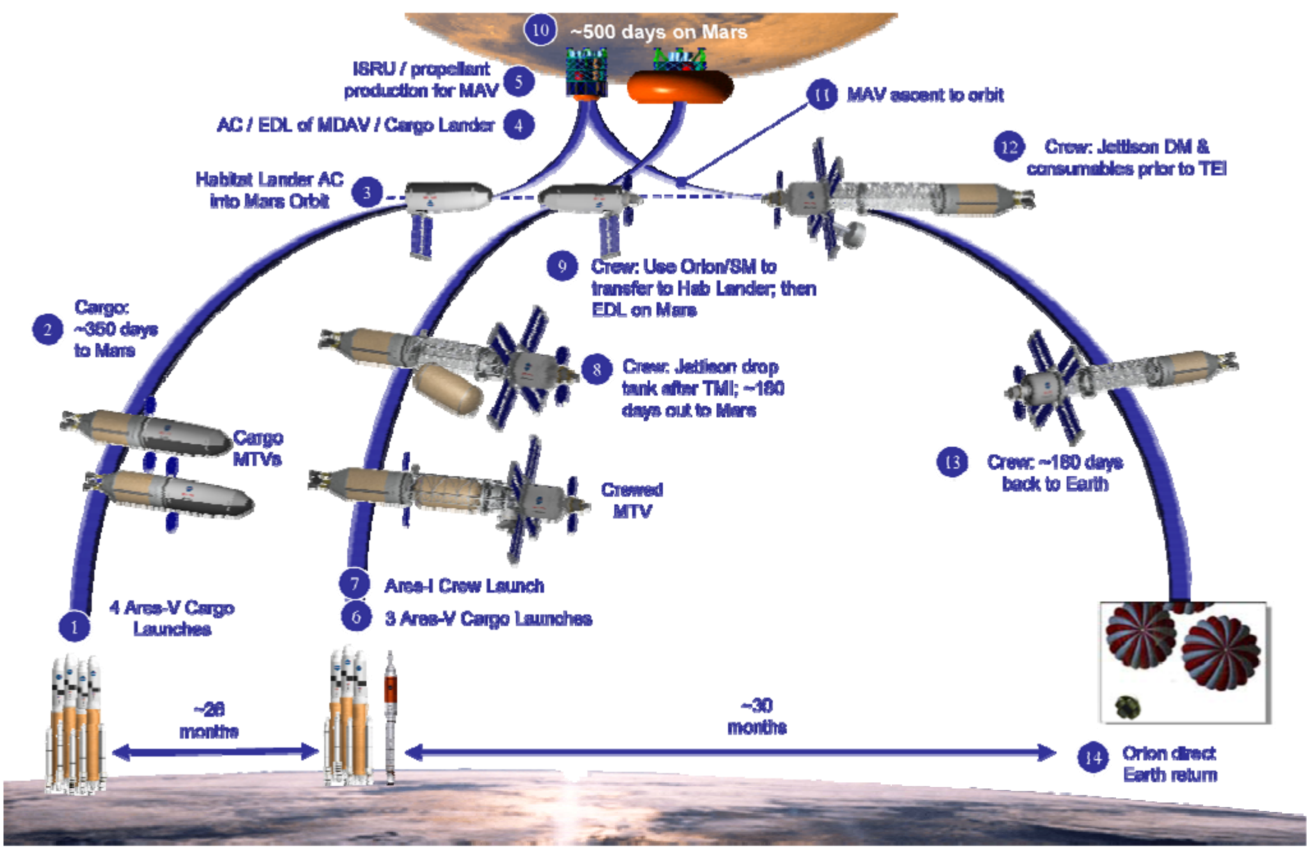

Figure 1 – Mars DRA 5.0 mission profile using nuclear thermal in-space propulsion

mission opportunity approximately 26 months later. Aerocapture is used to attain Mars orbit on the cargo missions, while propulsive orbit capture is baselined for the crewed mission. In-space propulsion is provided by nuclear thermal rockets (NTR).

To place the Mars Transfer Vehicle (MTV) and major payload elements in LEO, several modified versions of the Ares-V heavy launch vehicle with approximately 110-120 mT payload capability were studied. Four Ares V flights carried out over 90 days deliver the required components for the two cargo vehicles. The first two launches deliver the NTR core propulsion stages, each with a 10 m-diameter liquid hydrogen propellant tank and three 25,000 pounds force NTR engines. The next two launches deliver the cargo and habitat landers, which are enclosed within a large aeroshell that functions as payload shroud during launch, then provides lift and deceleration through the hypersonic phase for Mars orbit capture and subsequent entry, descent and landing (EDL) on Mars. Vehicle assembly involves Earth orbit rendezvous and docking (R&D) between the propulsion stages and payload elements with the NTR stages functioning as the active element in the R&D maneuver. The crewed MTV requires three 140 mT-class Ares V flights over 60 days to deliver its key components. The MTV's main components include a propulsion module, a saddle truss and liquid hydrogen drop tank, and the crew payload section, together totaling 326 mT. The crewed MTV payload section requires a large encapsulation shroud that measures approximately 12 m in diameter and 42.5 m-long. The cargo vehicle's aeroshell encloses the cargo and habitat landers. It measures 10 m in diameter and 33 m-long. To accommodate the varied surface payload elements on each lander a horizontal lander configuration is attractive, allowing the payload to be packaged along the entire length of the lander and payload deployment to be accomplished more easily.

3. OVERVIEW OF ARES V VEHICLE

Ares V Vehicle Options

In support of the lunar missions, thousands of Ares V conceptual designs have been assessed to determine the potential performance capability. The current baseline Ares V concept for the lunar missions was described during the Lunar Capabilities Concept Review (LCCR) – which functioned as the Ares V Mission Concept Review (MCR). The current reference configuration approved during the LCCR and referred to throughout this paper is designated 51.00.48. This vehicle is characterized by two 5½ segment polybutadiene acrylonitrile (PBAN) solid rocket boosters, a liquid oxygen/liquid hydrogen (LOX/LH_2) core stage utilizing six RS-68 engines, an Earth Departure Stage (EDS) utilizing a single J-2X LOX/LH_2 engine, and a standard biconic shroud which will be further described later. The Al/Li LH_2 tank in the Ares V core stage is 44.5 m long. The 51.00.48 vehicle is characterized in figure 2.

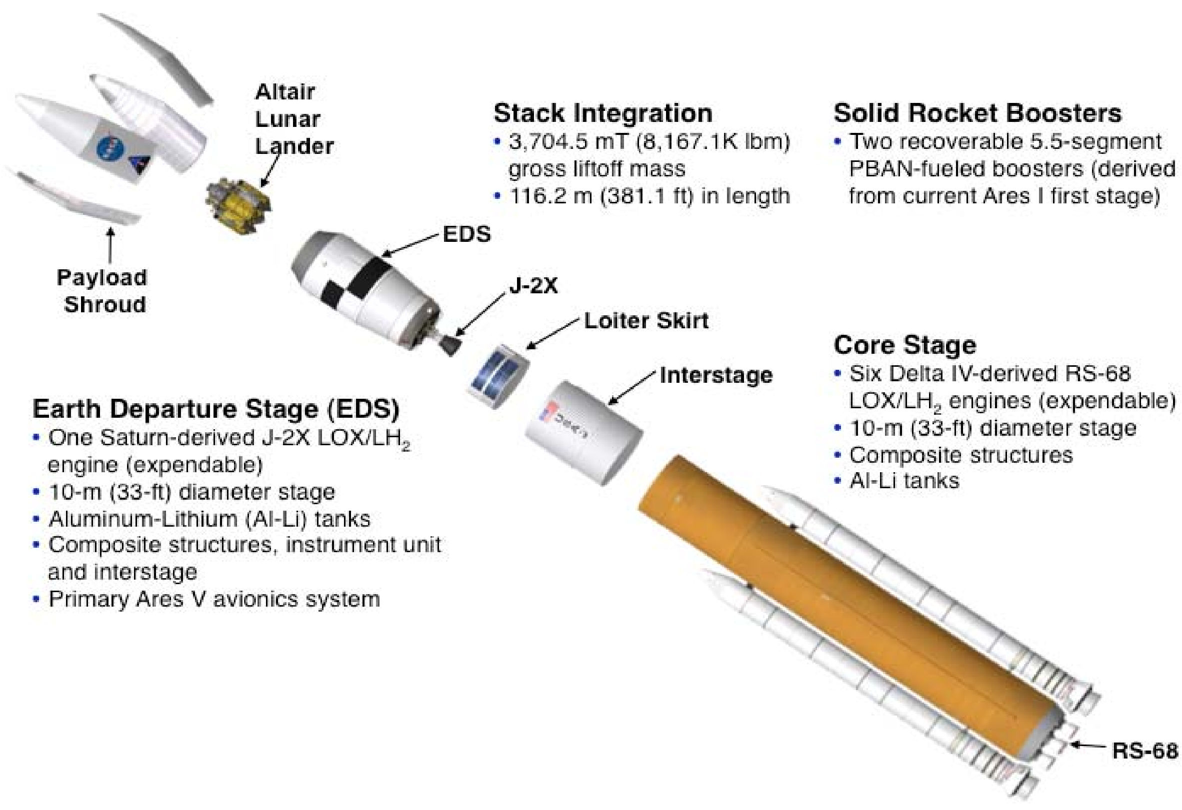

Figure 2 – LCCR 51.00.48 Ares V Concept

Analysis for the Mars Architecture Team (MAT) was performed before the LCCR. Therefore, the vehicles analyzed were pre-51 series. While there are minor differences in the ground rules and assumptions guiding the analysis, the primary distinction between earlier designs analyzed for the MAT and the current reference design is a diameter change in the EDS from 8.4 m to 10 m. Furthermore, the vehicles analyzed for the MAT vary the number and/or the type of solid rocket boosters (SRBs) – utilizing two LOX/LH_2 Delta IV Common Booster Cores in conjunction with two 5-segment PBAN boosters (45.0.5), four 5-segment PBAN boosters, or the more energetic HTPB propellant. In the other two concepts assessed for Mars applications, an intermediate stage is integrated between the core stage and the EDS. This intermediate stage utilizes the J-2X engine, while the EDS switches to the lighter and more efficient RL-10 engine.

Table 1 further describes the vehicles assessed for the MAT, as well as the current reference vehicle.

Ares V Vehicle Options – Performance Capability

When considering potential Mars missions without a defined assembly orbit, it is necessary to quantify the performance impact of delivering large payloads to various Earth orbits. For Mars DRA 5.0, the orbital altitudes assessed ranges from about 200 km up to about 1000 km. Figure 3 is similar to a chart shown in Mars DRA 5.0, which shows the performance of the early Ares V configuration to various altitudes (with three different shrouds). While the shroud options defined as “A, B & C” depicted in figure 3 (see page 5), on the next page, will be discussed in Section 4 of this paper, the important point is that the performance of the Ares V vehicle varies dramatically based on orbital altitude. Furthermore, the earlier reference configuration delivers between 80 and 135 mT, depending on shroud used and orbital altitude as shown in figure 3.

The relative performance to a 407 km circular orbit of the selected Ares V concepts is shown in figure 4 (see page 5). Using the earlier reference design as the study reference, the other Ares V concepts provided up to an additional 45 mT to LEO. This would represent a LEO capability ranging from approximately 125 mT up to about 170 mT at the 407 km circular orbit with the Option A shroud.

LCCR Reference Shroud Option

The shroud utilized on the current reference Ares V concept is a biconic shroud design constructed of composite materials. This shroud has the primary function of protecting the lunar lander during ascent to LEO. The shroud is jettisoned when the heating rate is reduced to less than 0.1 BTU/ft2-s. The LCCR reference shroud is 10.06 m in diameter, has a 9.7 m cylindrical barrel section, and has a nosecone of approximately 12 m. The nosecone section is divided into two truncated conical sections. The overall length from the tip of the nosecone to the interface with the forward skirt of the EDS is approximately 21.7 m.

The sizing structural load case for most structural members of the shroud is the maximum external pressure applied to the skin of the shroud during the Earth-to-orbit ascent portion of the flight trajectory. This maximum external pressure is most often referred to as the maximum dynamic pressure (or maxQ). For Mars missions though, aerocapture at Mars orbit insertion and EDL also must be analyzed as potential sizing load cases with the lateral and axial deceleration loads associated with the aerocapture and EDS phases of flight
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Table 1 – Key Attributes of Selected Ares V Concepts

	SRBs			Core Stage		2nd Stage		EDS	
Vehicle	#	Prop.	Segs	Dia.	# Eng.	Dia.	# Eng.	Dia.	# Eng.
51.00.48	2	PBAN	***5.5***	33’	***6***	N/A	N/A	***33’***	1
45.0.2	*2*	*PBAN*	*5*	*33’*	*5*	*N/A*	*N/A*	*27.5’*	*1*
45.0.5[3]	2	PBAN	5	33’	5	N/A	N/A	27.5’	1
45.0.13	***4***	PBAN	5	33’	5	N/A	N/A	27.5’	1
45.0.100	2	***HTPB***	5	***36’***	***6***	N/A	N/A	27.5’	1
46.0.100[4]	2	PBAN	5	33’	5	***33’***	***5***	27.5’	***5***
47.0.100[5]	2	PBAN	5	33’	5	***33’***	***4***	27.5’	***5***

[3] 45.0.5 vehicle also utilizes two Delta IV Common Booster Core boosters
[4] 46.0.100 vehicle has a “Short Core” Core Stage Configuration
[5] 47.0.100 vehicle has a “Long Core” Core Stage Configuration

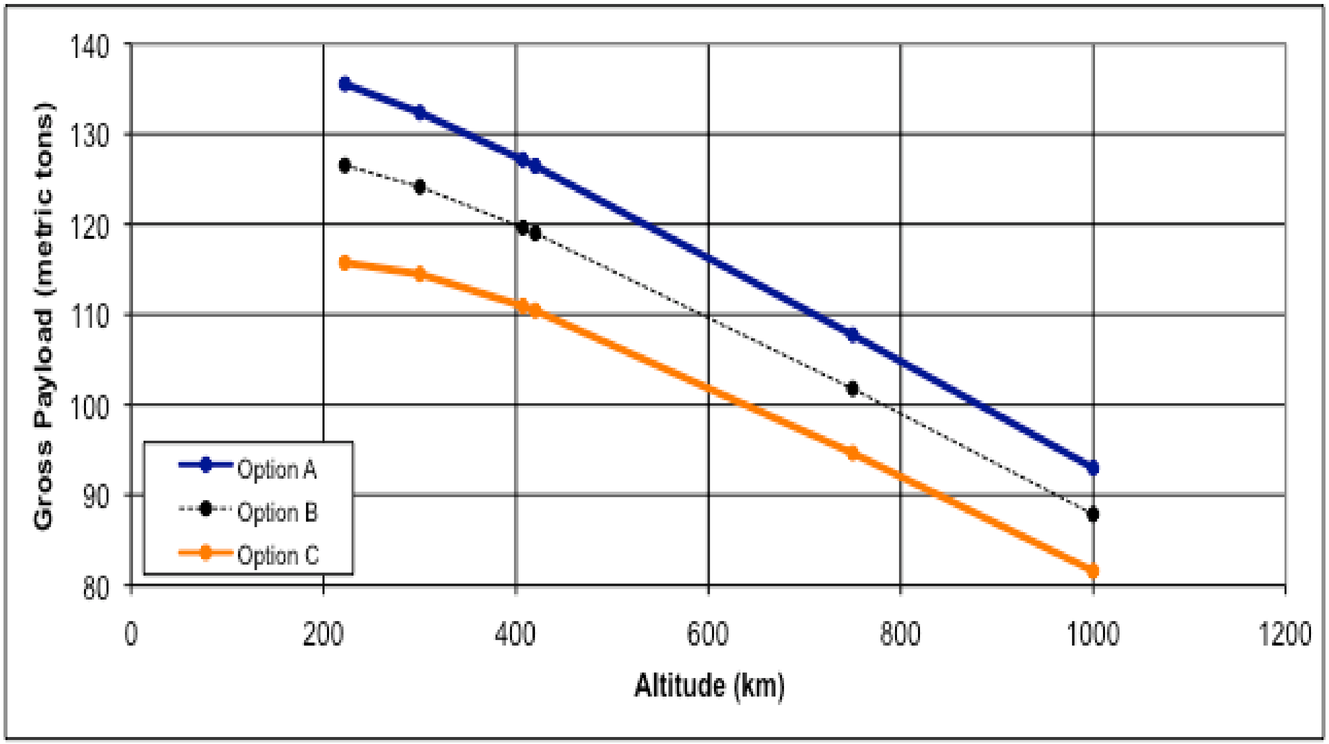

Figure 4 – 45.0.2 Ares V Performance vs. Orbital Altitude

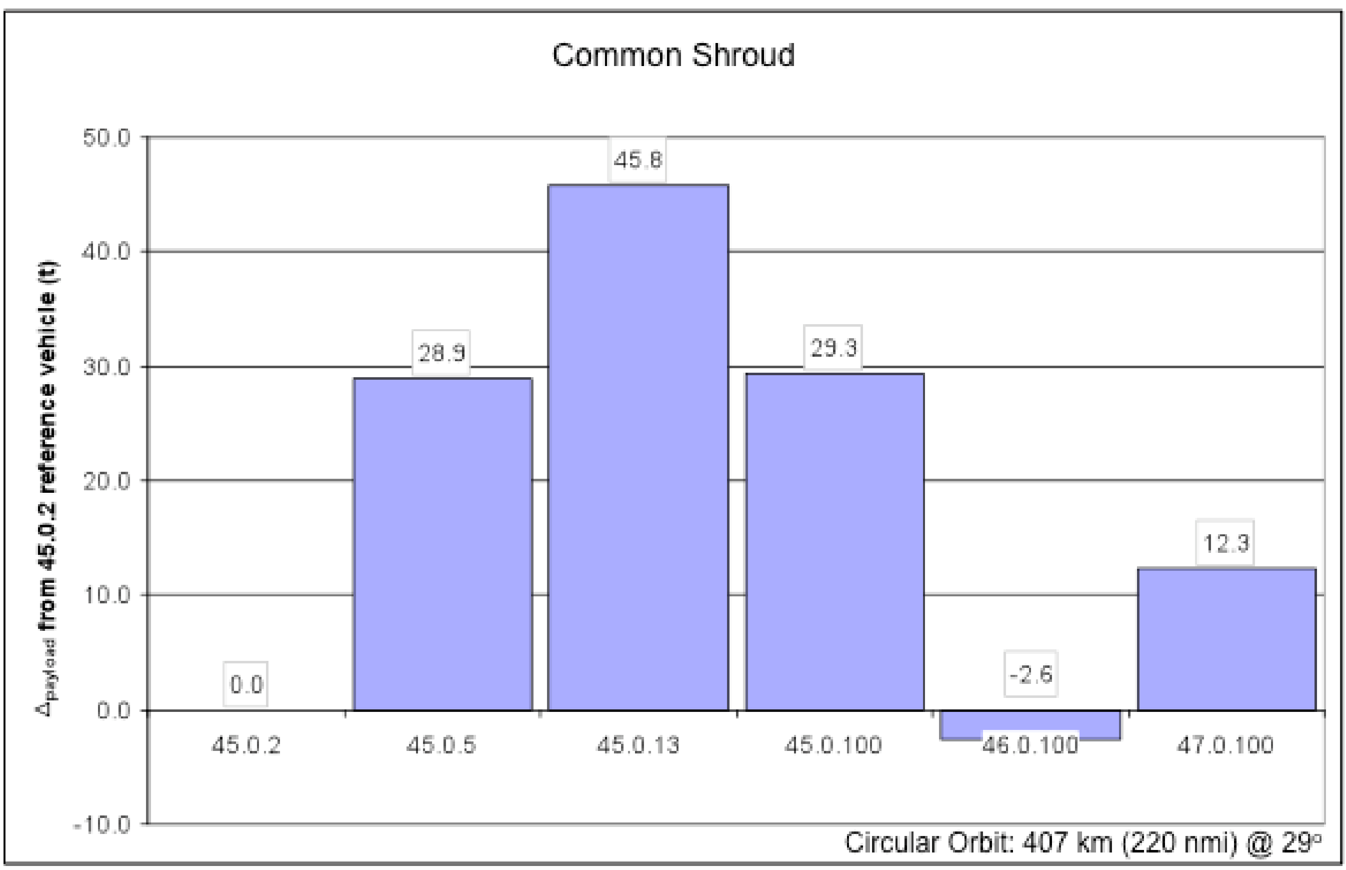

Figure 3 – Relative Performance of Ares V Concepts

Additional Lunar Mission Shroud Option

Since LCCR, the Ares V has transitioned from MCR into a requirements definition phase. As part of this process, several hundred potential shroud options have been assessed for performance, mass savings, acoustic environment attenuation, drag reduction, etc. A leading candidate for replacing the current baseline biconic design is a tangent ogive design of a similar geometry. While this potential shroud option is not used for comparative purposes in this paper, it should be noted that future analysis might transition to this design. It is also expected that this transition will not impact the potential for synergy between the Lunar and Mars shroud options, and the relative mass differences between the shroud options discussed later after incorporating this change will remain approximately the same.

4. CONCEPTUAL DESIGNS OF MARS SHROUD OPTIONS

For Mars DRA 5.0, five potential shroud options were analyzed. This includes three shrouds derived from the standard biconic shroud that was the baseline design at LCCR. These three options vary the outer diameter (OD) from 8.4 m up to 12.9 m and vary the total height from 22 m up to over 54 m in order to accommodate a wide variety of potential payloads. These "large encapsulation shroud" options are dubbed Options A, B & C. A fourth shroud analyzed is actually a portion of the biconic shroud design, which is envisioned for use on a possible Mars fuel stage delivery mission. It is merely the nosecone placed on top of the Ares V vehicle when there is not a payload to be encapsulated. In other words, the only "payload" is the propellant remaining in the EDS tanks once the vehicle is placed in Earth orbit. Finally, a fifth shroud option serves a variety of purposes. It functions as the shroud used for the Earth-to-orbit portion of the vehicle trajectory, but it also serves as the aerocapture shell for Mars orbit insertion. Furthermore, it is used during the Mars EDL phase to reduce aerothermal loads on the encapsulated payload.

Lunar Campaign Derived Biconic Options

The Option A shroud, shown in figure 5, is very similar in design to the LCCR reference shroud. The primary difference between these two shroud concepts is that the outer diameter for the Option A shroud is approximately 8.4 m as opposed to approximately 10 m for the LCCR 51.00.48 vehicle. In addition the barrel section of the Option A shroud is fixed at 12 m resulting in a 22 m overall length.

The Option B shroud, shown in figure 6, provides a larger payload volume than the Option A shroud concept. The outer diameter is increased from 8.4 m to 10.9 m, while the cylindrical barrel section is increased from 12 m to 25 m. With a fixed EDS diameter of 10 m, this increase in shroud outer diameter requires a transitional cone structure for proper integration. The transition cone is designed at a 30^{o} turning angle, and the mass of this structure is reported with the payload shroud. The overall length of the Option B shroud is approximately 40 m.

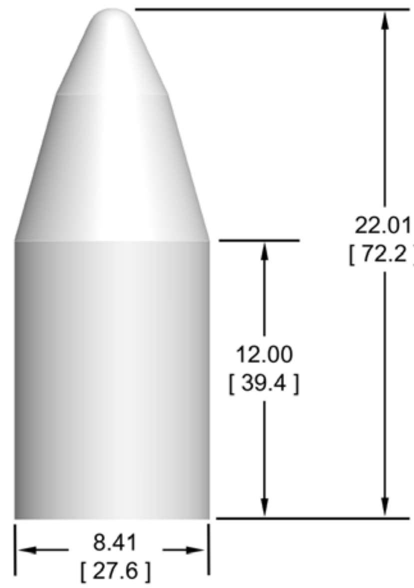

Figure 5 – Mars Shroud Option A

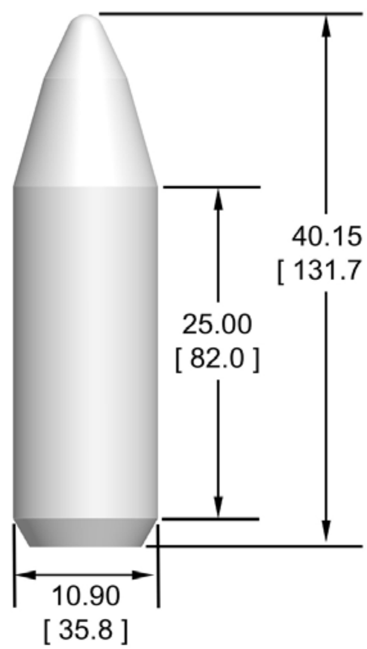

Figure 6 – Mars Shroud Option B

The Option C shroud, shown in figure 7, provides an even larger payload volume than the Option B shroud concept. The outer diameter is increased to 12.9 m, while the cylindrical barrel section is increased to 35 m. This larger diameter also requires a transitional cone structure for proper integration with the vehicle, but with a fixed 30^{o} turning angle the transition cone has a greater length than the transition cone required for the Option B shroud. The overall length of the Option C shroud is approximately 54 m.

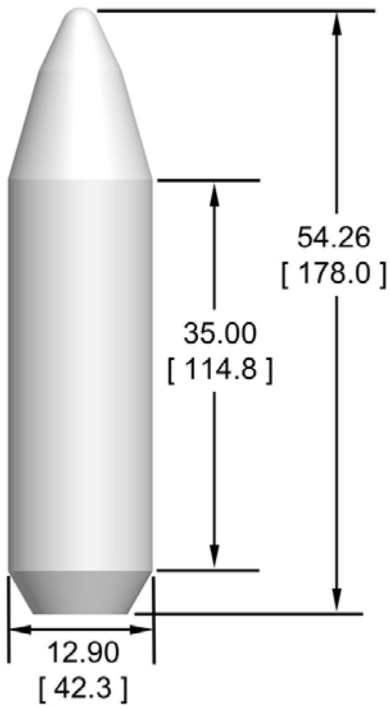

Figure 7 – Mars Shroud Option C

The large volumes provided by shroud options B & C are further shown in figure 8. Shroud options B & C would fully encapsulate the Space Shuttle Orbiter without the wings. Although large, the Option C shroud is reuqired to launch the human payload element of DRA 5.0, which has an 11 m OD and is 34 m long [2]. It includes the crew habitat module, a connecting saddle truss with attached contingency consumables canister and secondary docking module (DM), and a long-life Orion/Service Module (SM) for inter-vehicle transfer and capsule re-entry at mission end. Lastly, when mounted atop the current lunar Ares V, all of the Mars cargo and crewed payload elements exceeded the height restriction of the VAB (as shown by the dotted line) and will require an alternative method to the traditional stacking method currently used.

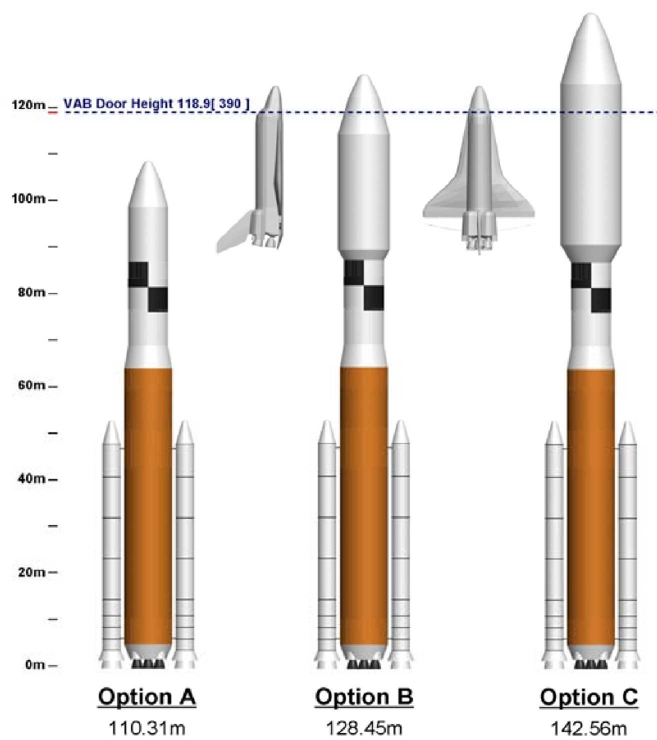

Figure 8 – Shroud Options A, B & C atop 45.0.2 Ares V

Shroud Options A, B & C were sized structurally by the Launch Vehicle Analysis tool at MSFC, while Integrated Rocket Sizing program (INTROS) Mass Estimating Relationships (MERs) were used for the mass allocations for both the thermal protection system (TPS) & acoustic blankets. The structural design of the shroud is primarily driven by the external pressure exhibited on the shroud during the period of maximum dynamic pressure (Max Q). As shown in figure 9, each of the vehicle options analyzed has a Max Q that varies from approximately 600 lb_f/ft^2 to over 800 lb_f/ft^2. The resulting total calculated shroud mass trends very closely with the differences in Max Q.

Figure 10 depicts the resulting total shroud mass for shroud options A, B & C. The total calculated mass for shroud option A ranges from approximately 13,000 lb_m to approximately 17,000 lb_m, shroud option B ranges from approximately 38,000 lb_m to approximately 45,000 lb_m, and shroud option C ranges from approximately 66,000 lb_m to approximately 78,000 lb_m. Obviously, the large increases in shroud mass result in a lower payload to orbit, as can be seen in figure 3. This is the classic launch vehicle tradeoff of less payload mass to orbit for more volume to orbit.

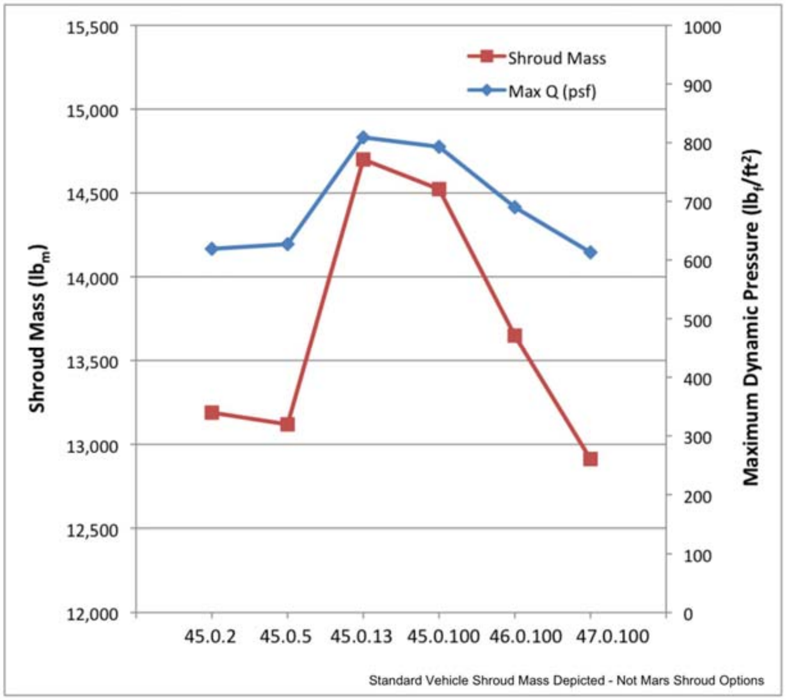

Figure 9 – Shroud Option Max Q Comparison

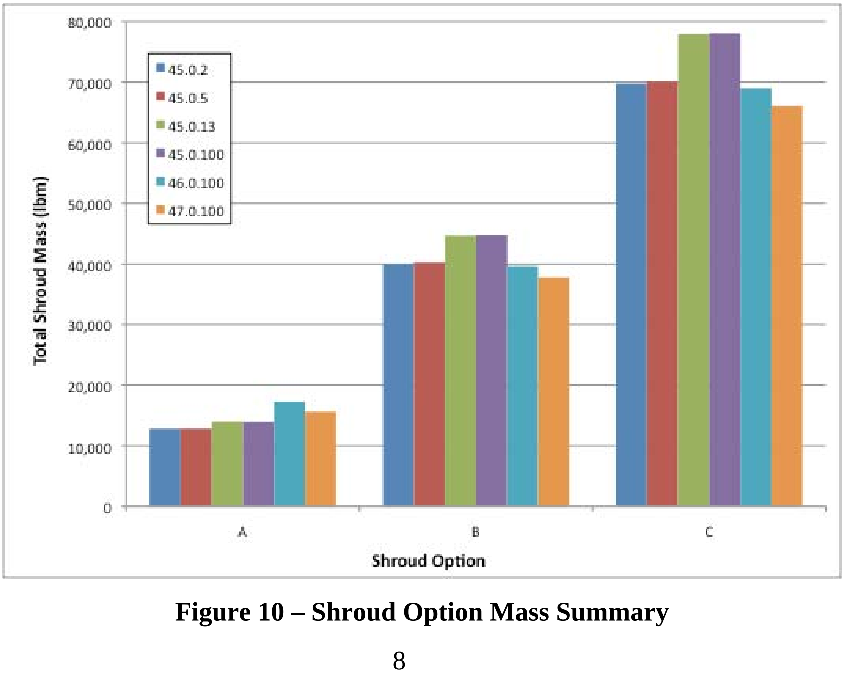

Figure 10 – Shroud Option Mass Summary

Mars Fuel Stage "Nosecone Only" Option

Potential scenarios for Mars missions requires large quantities of fuel delivered by the Ares V EDS. Whether this is delivered in the form of a full propellant tank encapsulated in the aforementioned payload shrouds or as a partially depleted EDS has yet to be determined. In order to deliver the maximum propellant remaining in the EDS, the minimum required shroud was designed for use in this propellant delivery scenario. This minimum shroud is basically the forward nosecone section of the standard biconic shroud as shown in figure 11.

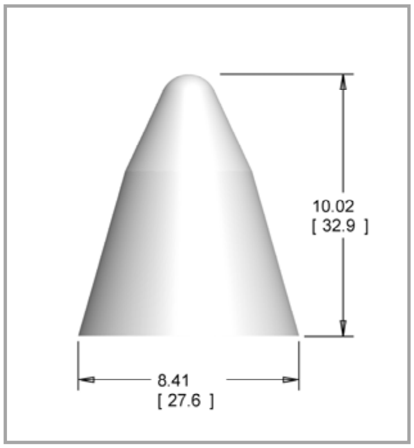

Figure 11 – Mars Fuel Stage Delivery Nosecone

Figure 12 depicts the total mass of this nosecone section that was designed & structurally sized using the LVA tool. Only TPS was required for this shroud, and this minimalistic design resulted in a much reduced total shroud mass. Overall, the total remaining propellant load that was delivered to LEO in support of the Mars missions ranged from approximately 112 mT up to about 148 mT.

Mars Multi-use Shroud Option

The multi-use shroud option, referred to in Mars DRA 5.0 as "dual-use shroud", is one that was determined from a system engineering functional analysis. The three major functions needed for certain Mars payloads are: 1. Earth-ascent encapsulation, 2. On-orbit environment protection, and 3. Planetary-entry thermal protection. A notional shroud with dark thermal protection system (TPS) tiles is shown in figure 13. For the three functions, it was determined that a multi-use shroud could provide an optimal benefit to the Mars exploration system.

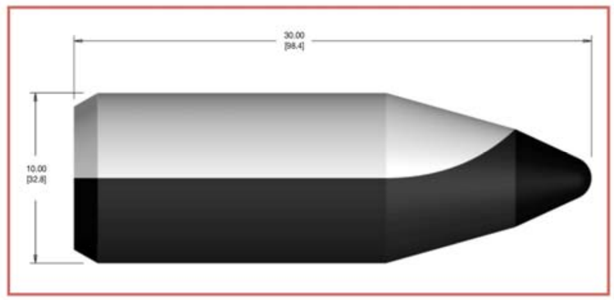

Figure 13 – Multi-use shroud concept image and cutline

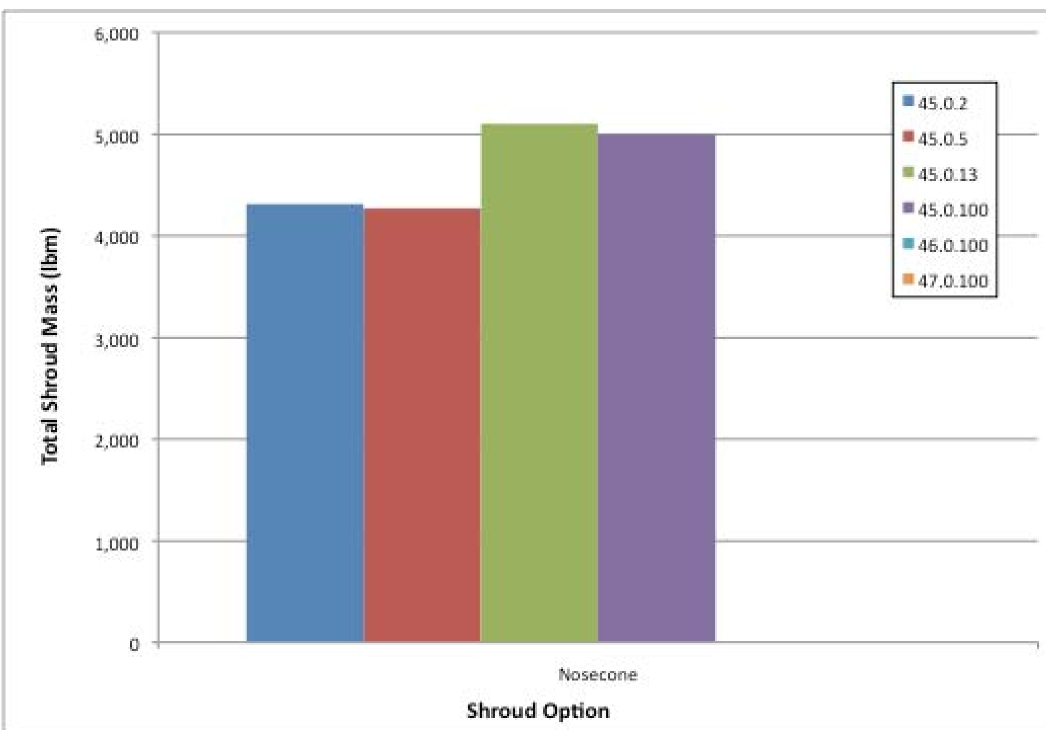

Figure 12 – Mars Fuel Stage Delivery Nosecone Mass

A shroud to protect the payload will be needed during ascent out of Earth's atmosphere. The shroud is normally discarded when atmospheric drag and ascent heat loads are sufficiently low to be considered safe to eject the aeroshell. The payload then is lofted as an exposed object to its on-orbit destination. For the human Mars mission, certain surface systems will be assembled on-orbit and then placed in an Earth-to-Mars transfer orbit. From there, crew will descend to the surface for the planetary part of the mission. Conceptually, the Earth ascent shroud could be strengthened and modified and lofted into LEO to provide: micro-meteoroid protection, and aero-thermal protection during the re-entry phase of Mars. This concept came to be known as a multi-use shroud.

This multi-use shroud was seen as advantageous, because it took advantage of all potential payload area and volume provided by the Ares V launch vehicle and increased effective payload mass to the Martian surface. The additions considered with this approach were a thickened composite sandwich with potential layers for mirco-meteoroid and orbital debris (MMOD) protection and an ablative thermal protection surface that could be used for Martian atmospheric re-entry.

Subsequent to the DRA 5.0 study, Entry, Descent, and Landing Systems Analysis (EDL-SA) was established specifically to identify promising technologies for accomplishing the portion of DRA 5.0 from Mars arrival to landing on the surface. During fiscal 2009, preliminary sizing and structural analysis of the shroud was performed for axial and lateral loads during aerocapture and entry, descent and landing (EDL).

The shroud used by the EDL-SA study is classified as a rigid mid-lift/drag (L/D) aeroshell, characterized by a straight barrel section with a hemispherical nose cap. However, trade studies are ongoing to find an optimum multi-use shroud configuration. Hemispherical, biconic and triconic are shown in this paper. The total length of the DRA 5.0 aeroshell is 30 m and the outside diameter is 10 m. The dual-use shroud consists of five subcomponents: structure, acoustic blanket, separation mechanism, body flaps, and TPS. Finite-element analysis (FEA) was used to estimate the structural mass, and a response surface (RS) was developed based on these estimates. The RS function included the following independent variables: diameter, length, arrival mass, maximum dynamic pressure, and maximum lateral and maximum axial decelerations. Mission environments influenced the development of the parametric mass models for the acoustic blanket and the separation mechanism. The mass for body flaps is a point design mass that is added to the aeroshell mass. The TPS is a dual-layer PICA-LI900, and the mass model is function of reference area and total heat loads for aerocapture and entry.

The mid L/D aeroshell configuration has body flaps for trim, and speed brakes for drag augmentation, though these features were not assessed in the initial analysis performed. The nominal L/D (lift-over-drag) is 0.5 at a hypersonic angle of attack of 55^o.

The aerodynamic and aerothermal models cover Mach 1.3 through 50, angles of attack of 0 through 90^o, and dynamic pressures of 1.E-7 through 0.75 bars. The aerodynamic models covers body flap deflections in the range of -10 to 50^o, and the speed brake for the range of 0 to 60^o. The aerodynamic model was developed by blending results from three separate levels of fidelity—linear (CBAERO), Euler (CART3D) and Reynolds-averaged Navier Stokes (DPLR). Over 600 high fidelity CART3D solutions were run on the baseline, as well as control surface deflected configuration. DPLR was run at a single (Mach 33) flight condition to anchor both the aerodynamics and aerothermal environments.

The approach velocities and target orbits for the cargo and crewed vehicles were provided by DRA 5.0. To summarize: 1) the hyperbolic approach velocity was set at 7.36 km/s; 2) the target orbit was 1 Sol (250 km x 33,793 km); 3) EDL initiates from the 1 Sol orbit; 4) the landing site is at 0 m altitude; 5) the touchdown provides 10 m accuracy; and 6) the deceleration profiles remain within those limits set for a de-conditioned crew (while allowing for dispersions). It was assumed for all the architectures that a reaction control system (RCS) would be the primary control. To emulate the characteristics of a RCS without having to design a control system, a "pseudo-controller" that modeled the bank acceleration, maximum bank rate, and bank direction was used.

Figure 14 shows the elements of aerocapture for a rigid aeroshell that flew at 55 deg angle of attack. This resulted in a ballistic coefficient of 490 kg/m^2, and an L/D of 0.43. The aerocapture evaluation used the HYPAS guidance algorithm to provide bank angle commands. Monte Carlo performance and sensitivity analyses were performed for both aerocapture and entry.

In addition to performing aerocapture as shown above, the multi-use aeroshroud must also perform EDL at Mars. This means it must withstand two heat pulses and aerodynamic loads. Figure 15, though showing an earlier shroud/lander configuration, graphically represents the timeline below 30 km for this second heat pulse. The vehicle simulation flew at 55 degrees angle of attack and had an L/D of 0.5. The results of the Monte Carlo analysis indicated Mach and

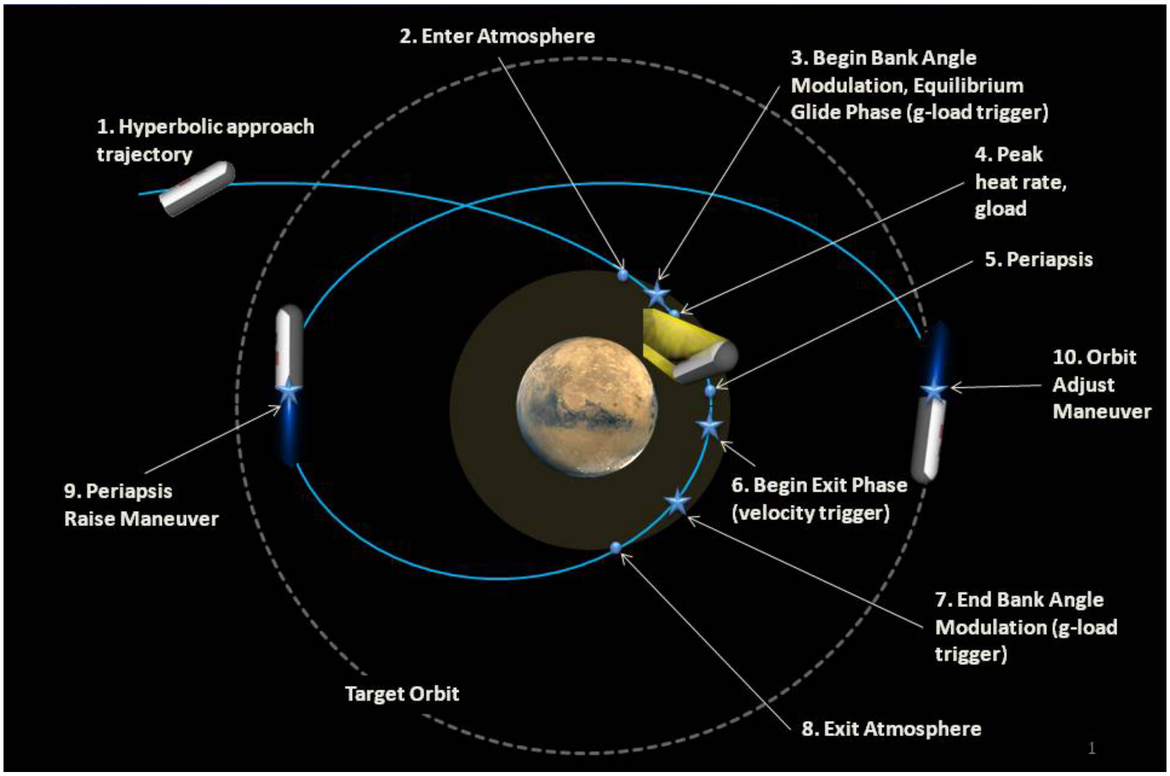

Figure 14 – Aerocapture Phases

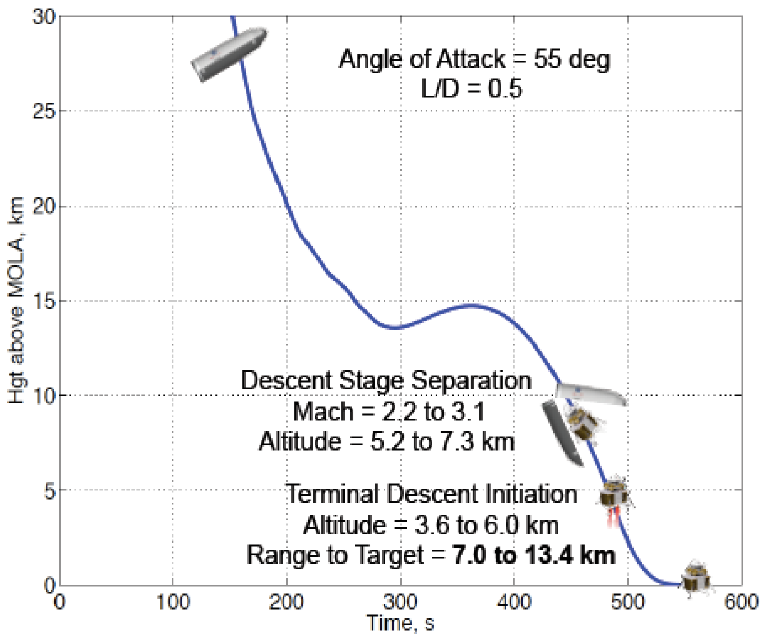

Figure 15 – Mars entry and landing phase

altitude dispersions at descent stage separation and terminal descent initiation. The 3-sigma dispersed values are denoted in figure 15.

TPS models furnished the sizing analysis of the thermal protection systems needed on the rigid mid-L/D aeroshells used for the aerocapture and entry phases. The sizing analysis is based on the tools and practices developed by the Orion TPS ADP. The TSP sizing tool was extended for EDL-SA to include the capability to size dual layer TPS.

TPS masses for a forebody heat shield made of a single material (PICA) were very large. EDL-SA's TPS experts conceived a dual-layer TPS with the PICA ablator atop a low thermal conductivity substrate such as the Shuttle tile material or SLA 561. Individually, these TPS materials are at a high TRL, but a dual layer TPS system made of these materials has never been evaluated or tested. Hand analysis of the dual layer concept at three body points indicated that the concept could reduce TPS masses by about 27 percent, not accounting for attachments. Using the new sizing code to do entire body TPS sizing, the concept for PICA atop the LI-900 Shuttle tile material was shown to be capable of reducing the windward TPS mass by 37%, not accounting for TPS attachments or weight-growth allowance. Viability testing revealed that PICA performed exactly as predicted for the first pulse at ~500 W/cm^2. Tests allowing burn-though of the PICA into the LI-900 showed that the latter slumps (shrinks). Avoiding burn-through can be accomplished by leaving some PICA on the dual layer stack at the end of the first (aerocapture) heat pulse and prior to the second heat pulse (entry). These thicknesses cannot be accurately estimated at this time for a flight case owing to lack of knowledge of PICA's recession at low heat fluxes. The question of how robust the charred PICA will be when exposed to the second pulse (entry) remains to be answered by an arc jet test at ~ 120 W/cm2 corresponding to the out-of-Mars entry heating. Viability testing of a new ~2" honeycomb attachment for PICA atop LI-900 was also was also conducted. The honeycomb functions as intended for the dual heat pulse application and is included in the current mid-L/D mass estimating relationships (MERs). Both NASA's Aeronautics Research Mission Directorate (ARMD) and Exploration Systems Mission Directorate (ESMD) are investing in several materials concepts that may improve the efficiency and robustness of the dual-use TPS solution.

More detailed finite element modeling would obviously be needed to refine these estimates. The preliminary sizing and loads analysis did allow for some first order mass penalties and knockdown factors to be developed and carried as part of the systems analysis. It is likely that with the complex multi-use role, additional interface protuberances and various structural attachment points will be added that make the potential mass of the multi-use shroud heavier.

However, the current conceptual model takes into account separation systems that would not be necessary. Also, it was considered that certain material choices that could increase the mass may also provide a degree of environment protection for cosmic background radiation and/or solar wind. Overall, the concept of a multi-use shroud was found to have several advantages, but there would be some additional complexity associated with the

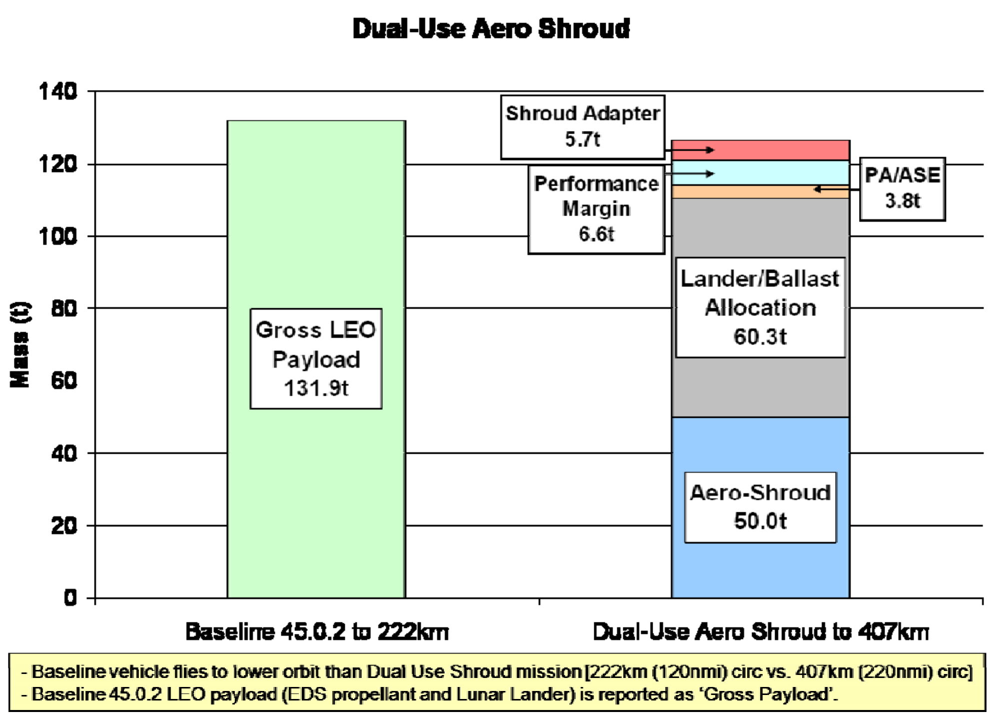

Figure 16 – Impact of dual-use aeroshroud on overall Mars payload mass

encapsulation system.

Notably, the assumed mass for the multi-use shroud was about 50 mT, and that would impact the mass of the payload that it is encapsulating. This would obviously result in less available payload mass to be encapsulated when compared to traditional shrouds. This payload reduction is further compounded because the dual use shroud is injected into LEO with the payload, rather than being jettisoned during launch. Nevertheless, the Ares V concept assessed for DRA 5.0 could accommodate more than 60 mT of payload mass, in addition to mass allocations for the 50 mT shroud, performance margin, any required payload adapters and airborne support equipment, and a shroud adapter. This is shown graphically in figure 16.

Because of the use of an aeroshell, this approach is considered the highest TRL of the drag devices assessed by the EDL-SA for landing large payloads on the surface of Mars. Several technology challenges remain including aeroshell design and materials, payload packaging, detailed modeling of the separation event and engine initiation at supersonic velocities. A preliminary look at packaging has been made for the 10 m x 30 m aeroshell. Additional analysis is desirable to determine if a larger volume aeroshell may be required to provide the ballistic coefficient to decelerate and land the payload mass identified in DRA 5.0. Further analysis is also warranted to determine whether the payload should be packaged into a vertical or horizontal lander or whether additional cargo landers might be required.

5. LUNAR/MARS SHROUD OPTIONS SYNERGY

The lunar mission payload envelope is currently the driving factor for the sizing of the Ares V reference shroud. In general, this sizing is driven by the dimensions of the lunar lander carrying lunar surface cargo. This reference lunar shroud is significantly larger than any shroud flown to date, but it is still inadquaate for use in NASA's Mars DRA 5.0.

The various analyses presented and discussed in this paper indicate the need for both scaling up the lunar reference shroud for use in future human Mars missions plus the value of developing a multi-use shroud. Functioning as a payload faring during launch, providing in-space support to the payload during transit, along with thermal protection and entry deceleration during aerocapture and subsequent EDL, the multi-use shroud offers the potential to deliver and land large payloads on Mars with reduced development costs. Propellant tankage can also be launched un-encapsulated with a nose-cap only option if required.

Overall, the approaches discussed here build on the lunar test-bed philosophy of Constellation by developing and validating launch aerodynamic and heating environments during initial Ares V operations in support of lunar missions, simplifying the design requirements for the Mars elements. If the decision is made to develop a scaled up conventional shroud for Mars, to increase payload volume and reduce the subsequent launch count, the reference Ares V shroud subsystems should be fully useable with an appropriate test program.

6. CONCLUSIONS

The NASA DRA 5.0 architecture has shown a need for large encapsulation shrouds beyond what is envisioned for the current lunar capability. Shrouds on the order of 12 m in diameter with a cylindrical section just under 30 m appear necessary to enable a reasonable number of launches for a Mars mission. A payload shroud with the capability to re-enter and land on Mars has at the first order shown a mass and packaging benefit for future missions. Some key needs from the launch vehicle side would be the maintenance of a 10 m LH_2 tank diameter in the Ares V core stage for synergy with the NTR transfer stage, also the need to examine a smaller orbit injection stage in place of the current large EDS to reduce overall vehicle height and allow a longer shroud. In conclusion, investments appear warranted to support the development and fabrication of large scale composite structures, thermal protection systems, and the facilities needed to test and qualify them, as well as computational tools for predicting the environments and flight performance of this large vehicle. The Mars DRA 5.0 study has identified the shroud requirements needed to establish a human presence on Mars. It is important that they be considered in the development of any future heavy lift capability.

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[2] 7 Launch NTR Space Transportation System for NASA's Mars Design Reference Architecture (DRA) 5.0, Stanley K. Borowski, David R. McCurdy and Thomas W. Packard, AIAA-2009-5308, 45th AIAA Joint Propulsion Conference and Exhibit, August 2-5, 2009

BIOGRAPHIES

Stuart Feldman provides support to the NASA Ares Projects Office and the NASA Constellation Program, in the areas of System Architecture, Design Integration, Conceptual Design, and Systems Analysis. Mr. Feldman represented the Launch Vehicle team on the development of Mars Design Reference Architecture 5. Mr. Feldman holds a B.S. in Aerospace Engineering and a Masters of Engineering in Space Systems, both from the University of Michigan, as well as an MBA from Pepperdine University. He is currently an Owner of Zero Point Frontiers Corp. in Huntsville, AL.

Dr. Stan Borowski is a senior aerospace / nuclear engineer and branch chief of the Propulsion & Controls Systems Analysis group at NASA's Glenn Research Center. During his past 21 years, he has been GRC's technical lead for all human and robotic space transfer vehicle design and analysis activities involving the use of Nuclear Thermal Rocket (NTR) propulsion for exploration missions to the Moon, Mars, near Earth asteroids (NEAs) and the outer planets. His latest responsibilities in this area included leading the NTR space transportation analysis team during NASA's recent Mars Design Reference Architecture (5.0) study.

Walter (Walt) Engelund is the Langley Chief Engineer with the NASA Engineering and Safety Center. He has over 20 years experience with NASA, conducting aero-dynamic assessments and developing atmospheric flight systems for a wide variety of concepts and configurations in all flight regimes, including expendable and advanced reusable space transportation systems, planetary entry probes, and hypersonic flight demonstrator vehicles. In 2007-08 he served as the Co-lead for the Agency's Mars Design Reference Architecture 5.0, Entry, Descent, and Landing (EDL) team, and helped define the future Constellation enabled human Mars architecture and mission set.

Jason Hundley provides support to both the Ares Projects Office at NASA MSFC and the NASA Constellation Program. Since receiving a B.S. in Physics and Mathematics from Wright State in 1998 and a Masters Degree in Mechanical Engineering from The George Washington University in 2001, he has been involved in numerous programs in the defense and space industries. He is currently an Owner of Zero Point Frontiers Corp. in Huntsville, AL.

Timothy Monk is a Systems Integration Engineer in the Ares Projects Office at NASA Marshall Space Flight Center. He is a 2005 graduate of Auburn University and a 2006 graduate of the University of Colorado receiving a Bachelor's and Master's Degree in Aerospace Engineering, respectively. Since joining NASA in early 2007, he has performed numerous trades and analysis on the Ares V concept and potential mission scenarios. He is an engineer at Zero Point Frontiers Corporation.

Michelle Munk has worked for NASA for over 20 years, in the areas of interplanetary trajectory design, atmospheric entry flight dynamics, flight hardware engineering, and technology management. Since 2002, Ms. Munk has supported NASA's Science Mission Directorate as Lead Systems Engineer and Manager for Aerocapture Technology Development. She also supports systems analysis studies identifying needed technologies for future human Mars exploration.

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Analysis of Shroud Options in Support of the Human Exploration of Mars

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Presented by Bret Drake, JSC

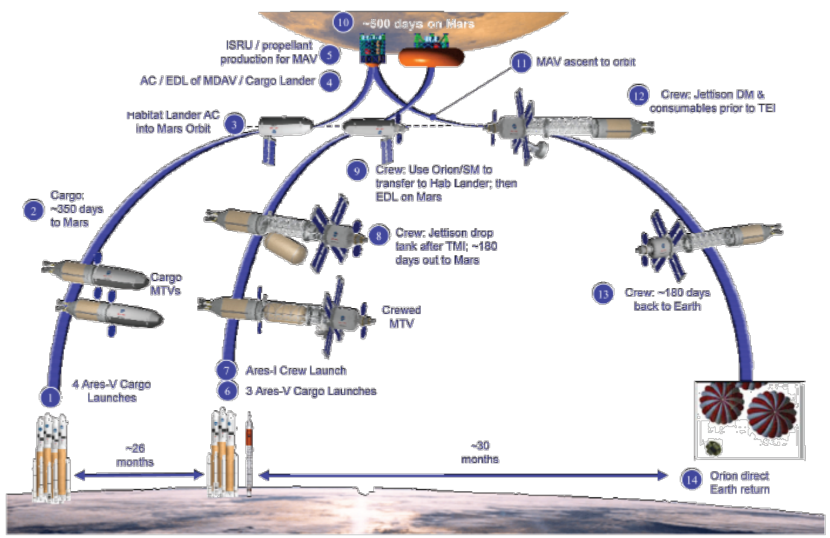
March 10th, 2010

Agenda

- Overview of Mars Mission
  - Mars Design Reference Architecture (DRA) 5.0
- Overview of Ares V launch vehicle
  - Performance capability enabled by selected Ares V concepts
  - Current lunar campaign shroud
- Conceptual designs of potential Mars shroud options
  - Scaled lunar shrouds
  - Fuel delivery option
  - Multi-use shroud option
- Lunar Mission/Mars Mission shroud options synergy

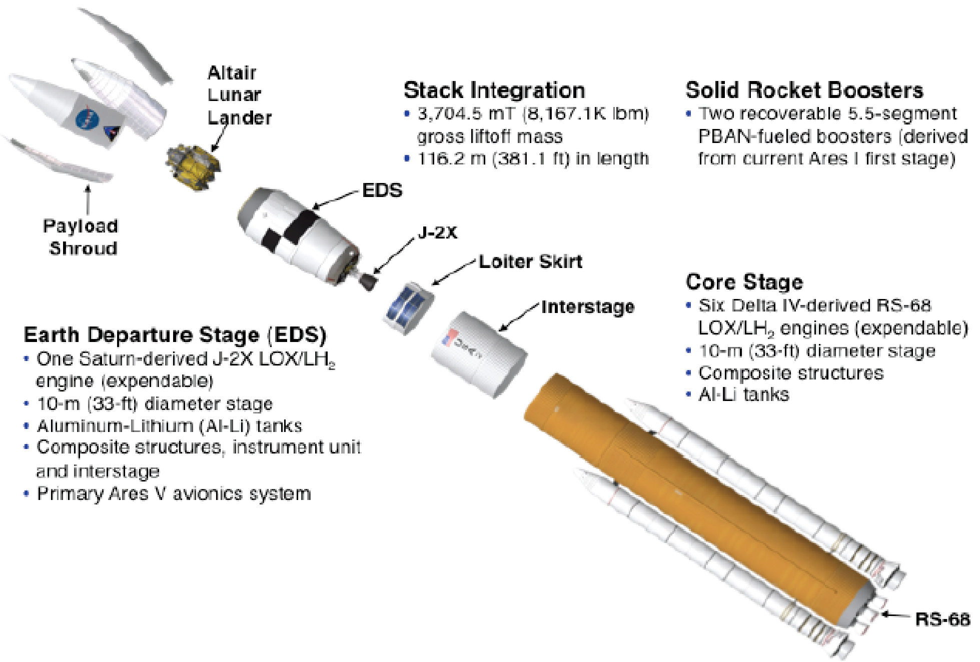
Mars Mission Concept

- Mars DRA 5.0 publically released July 2009
- On the order of 125 t per launch to LEO
- At least 7 Ares V launches required per mission (when coupled with Nuclear-Thermal Propulsion (NTP) for in-space propulsion)
  - 2 launches x 2 for pre-deployment of “cargo” assets (~2 years before crew)
    - Descent/Ascent Vehicle (DAV) + NTP element for Trans-Mars Injection (TMI)
    - Surface Habitat + NTP element for TMI
  - 3 launches for crew Mars Transfer Vehicle (MTV) + Crew Launch Vehicle
    - NTP element + NTP propellant for TMI + crew MTV
    - Ares I crew launch will deliver 6 person crew after the 3 Ares V MTV launches



Overview of Ares V

- Concepts assessed for Mars DRA5.0 were characterized largely by a 10m Core Stage diameter powered by RS-68B engines, an 8.4m Earth Departure Stage powered by a single J-2X engine, and two Solid Rocket Boosters (SRBs).
- The recommended Ares V Point-of-Departure (POD) vehicle maintained much of the same major parameters with the exception of a larger diameter EDS and shroud (10m).



Ares V POD (LV 51.00.48)

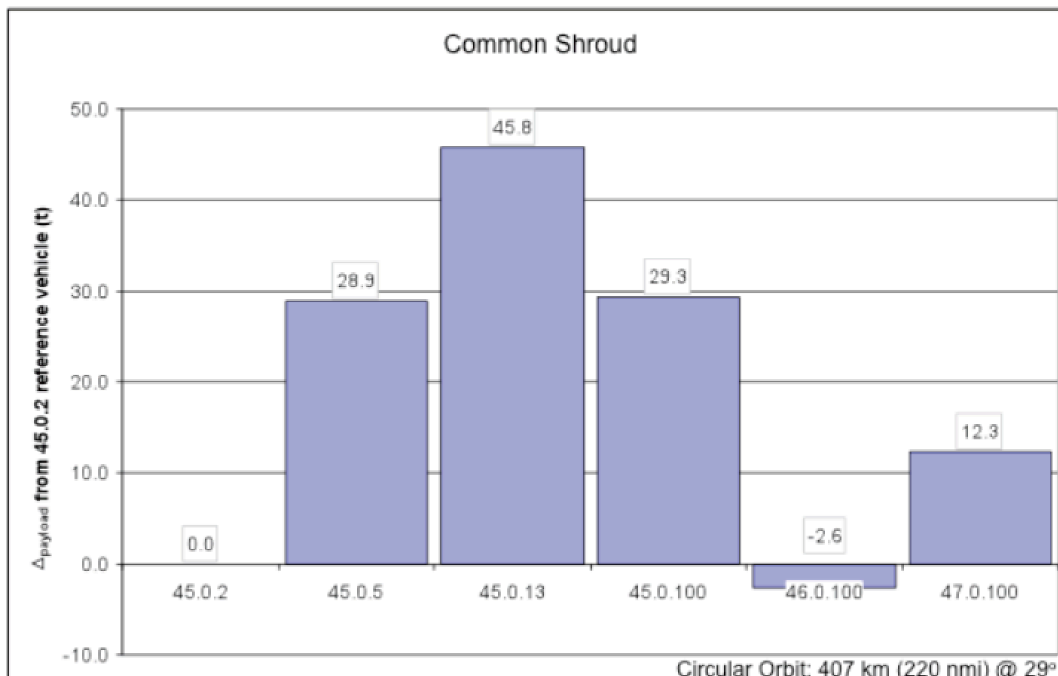
Ares V Performance Capability

- **Selected "performance upgrade" options were assessed to provide the potential for larger payloads or higher altitudes, if required**

	SRBs			Core Stage		2nd Stage		EDS	
Vehicle	#	Prop.	Segs	Dia.	# Eng.	Dia.	# Eng.	Dia.	# Eng.
51.00.48	2	PBAN	5.5	33'	6	N/A	N/A	33'	1
45.0.2	2	PBAN	5	33'	5	N/A	N/A	27.5'	1
45.0.5[3]	2	PBAN	5	33'	5	N/A	N/A	27.5'	1
45.0.13	4	PBAN	5	33'	5	N/A	N/A	27.5'	1
45.0.100	2	HTPB	5	36'	6	N/A	N/A	27.5'	1
46.0.100[4]	2	PBAN	5	33'	5	33'	5	27.5'	5
47.0.100[5]	2	PBAN	5	33'	5	33'	4	27.5'	5

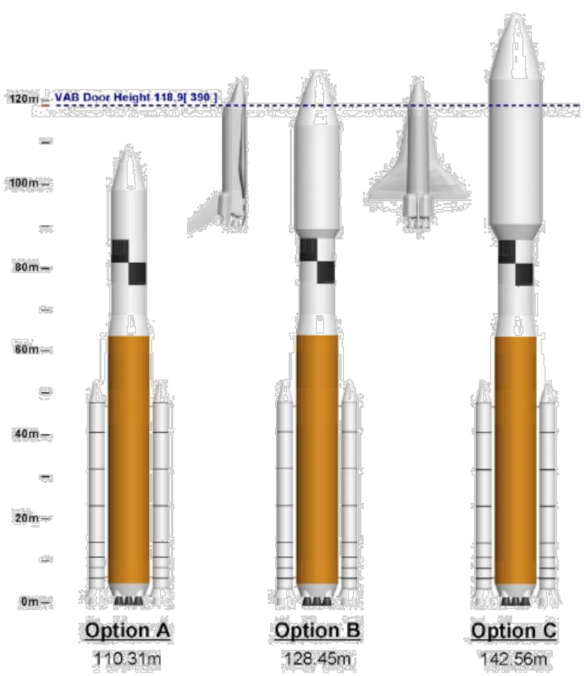
[3] 45.0.5 vehicle also utilizes two Delta IV Common Booster Core boosters
[4] 46.0.100 vehicle has a "Short Core" Core Stage Configuration
[5] 47.0.100 vehicle has a "Long Core" Core Stage Configuration

The 45.0.2 vehicle was considered the 'reference vehicle' for DRA5.0

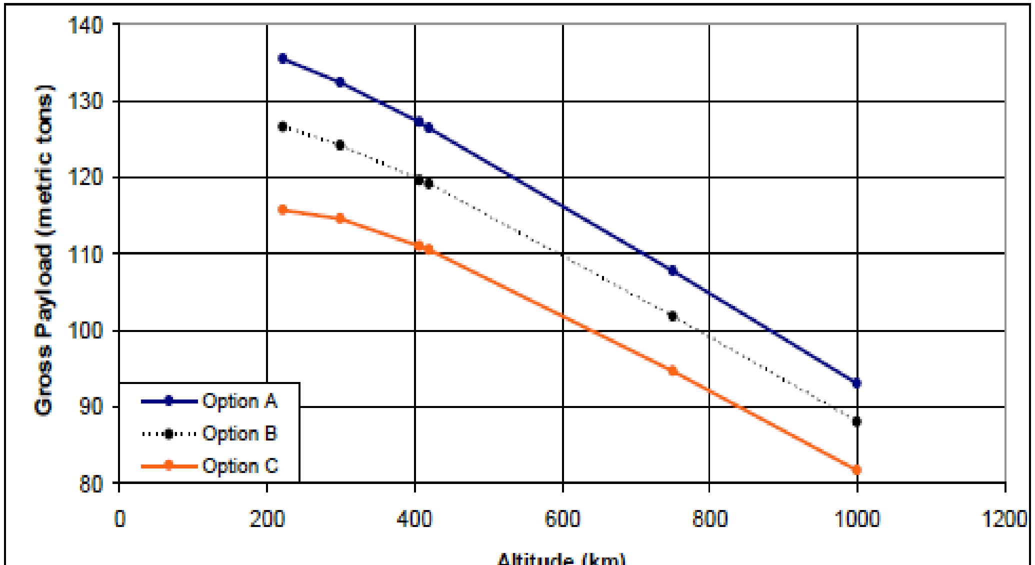


Ares V Performance Capability – cont.

- The Ares V provides a unique lift capability to LEO in support of Mars missions
- Mars DRA 5.0 assumes a lift capability of 125 t to LEO
- Performance was assessed using a wide variety of shroud options to various LEO altitudes at a 28.5º inclination



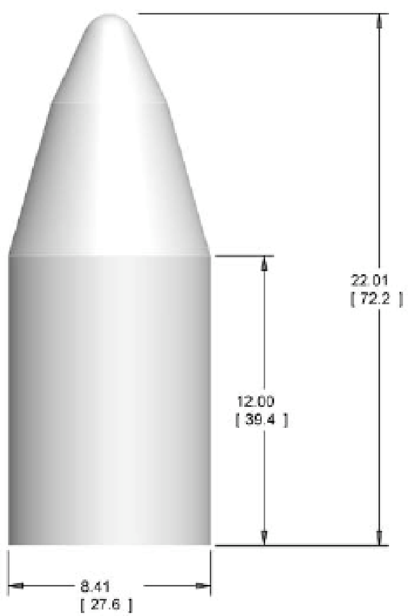
3 potential shroud options



Reference 45.0.2 Ares V configuration

Mars Shroud Options – Lunar Reference Shroud

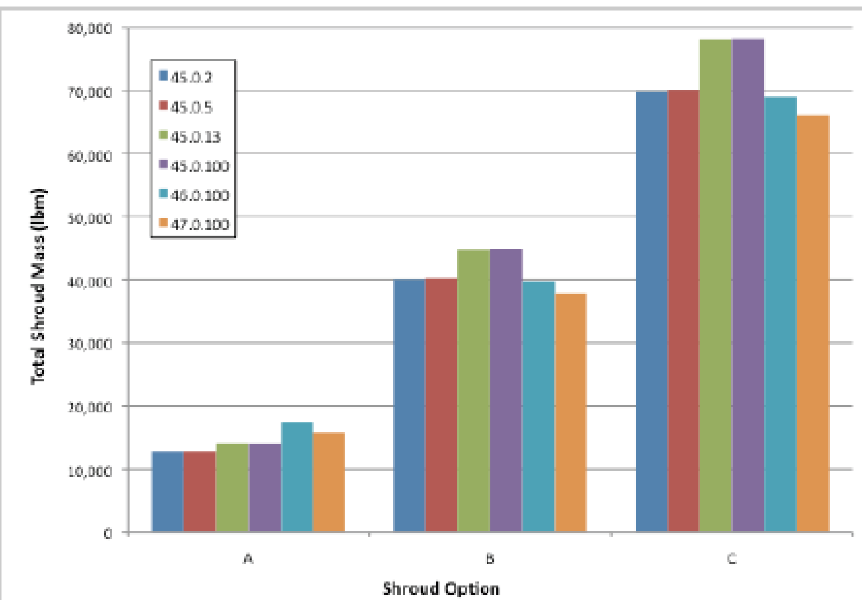
- **The lunar campaign reference shroud, also depicted as the Option A shroud, is a bi-conic design**
- **IM7/8552 composite materials are incorporated**
- **Outside diameter is 8.4m (commonality with EDS)**
  - Additional analysis on acoustic environment resulted in a 7.5m usable diameter (less material thickness, structural support, acoustic blankets, etc.)
- **POD increased outer diameter to 10m along with the EDS to increase usable diameter for the payload, increase commonality among the elements, and decrease structural mass required to support a variable diameter.**



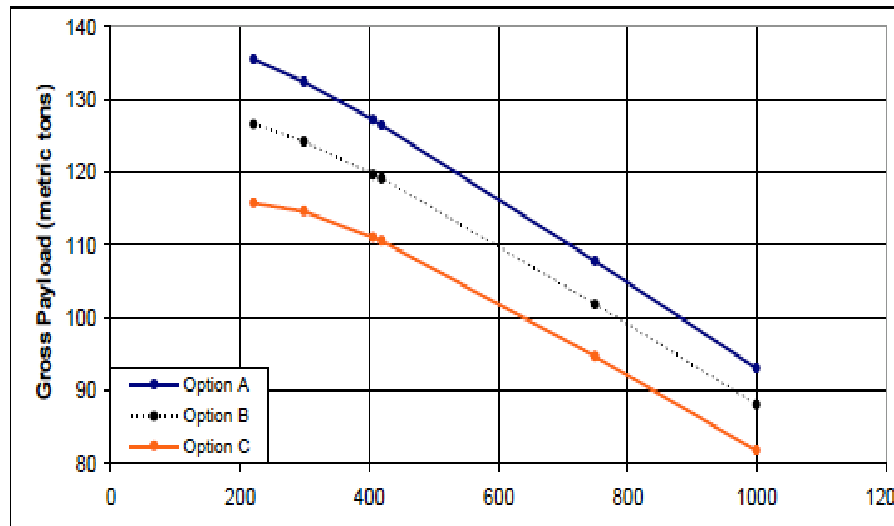
- **Jettisoned during Earth-To-Orbit ascent when heating rate is <= 0.1 BTU/ft^2-s**
- **Quad-petal design**
- **Structurally sized by external pressure applied through ETO ascent**

Scaled Lunar Shrouds for Mars Mission Support

- **Initial analysis focused on scaling up the lunar reference shroud to enable larger volumes in support of Mars missions**
- **Not only did these shrouds exceed the door height limitations at the VAB, the mass of these shrouds resulted in a large mass decrement to the potential payload mass injected into LEO**



Mass increased to nearly 80 klbm for the Option C shroud

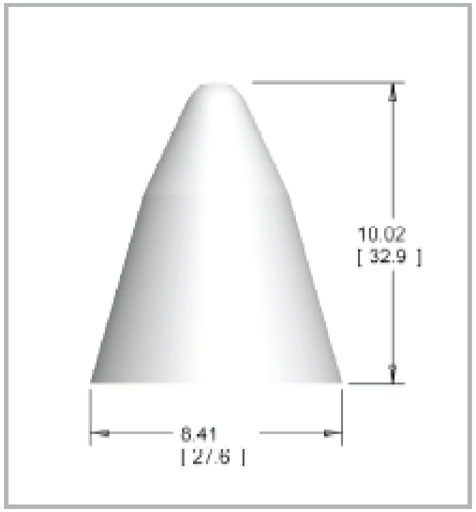


Reference 45.0.2 Ares V configuration

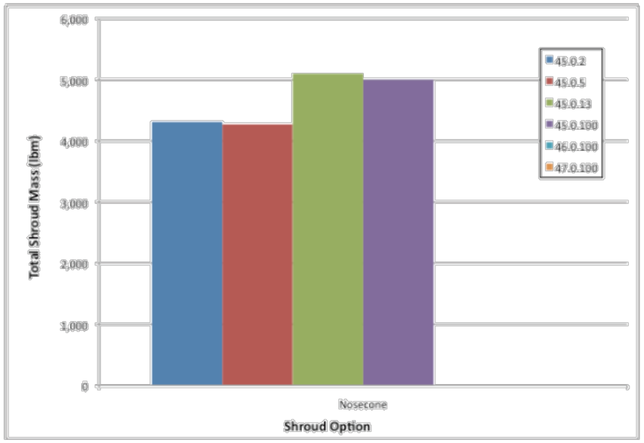
As shown previously, the mass decrement was ~6% for the Option B shroud and ~14% for the Option C shroud

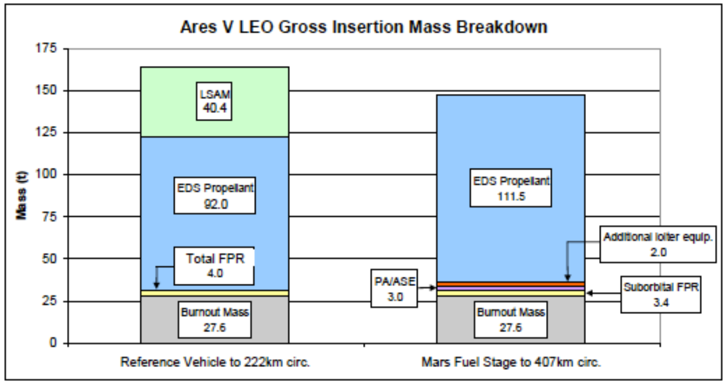
Fuel Delivery Option – Nosecone Only Option

- Certain mission concepts introduced a unique mission requirement on the Ares V for fuel delivery to LEO
- This could be a scenario where no payload was launched on the vehicle, but delivery of the maximum amount of “remaining propellant” in the EDS tanks was desired
- Another potential scenario would be the launch of a NTP propellant tank and an aerodynamic nosecone was utilized for ETO ascent
- In support of DRA 5.0, this nosecone was sized structurally utilizing the same techniques as the lunar shroud without the cylindrical barrel section



Mass of the nosecone is typically < 5 klb$_m$

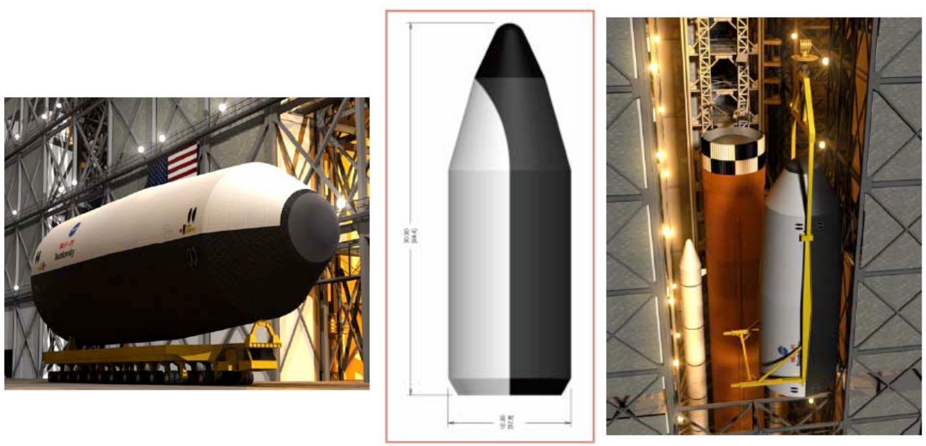




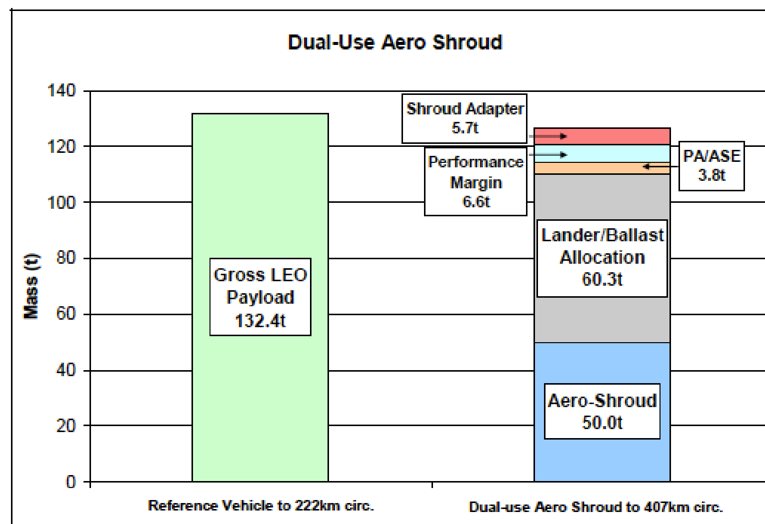
Lunar mission launch a lander and TLI prop to LEO, whereas propellant remaining in the tank at LEO insertion can be optimized as well

Multi-use Shroud Option

- From a Mars mission systems perspective, an interesting solution was the utilization of a "multi-use" shroud (referred to as the "dual-use shroud" in DRA 5.0)
- Not only would the shroud protect the payload during ETO ascent (and be retained to orbit), but it would also serve as the aerocapture device at Mars arrival
- Used during the entry, descent, & landing (EDL) phase for thermal protection
- Provides additional thermal & MMOD protection during Mars transit



Early depictions of the multi-use shroud



Performance of the vehicle with a 50t multi-use shroud

Lunar/Mars Mission Design Synergy/Conclusions

- **Options have been explored that would utilize a similar shroud as that currently baselined for use during the Human Lunar Return**
- **In addition, using a portion of the current lunar shroud for Mars fuel delivery missions has been assessed**
- **An interesting system solution that has been further assessed (and is a key technological development) is the multiuse shroud**
  - Offers ETO ascent, Mars arrival, Mars EDL, and in-space environment protection
- **Builds on the Constellation Program's "Lunar Test Bed" philosophy**
  - Develop and validate launch environments during lunar campaign
  - Extensible to Mars mission design requirements

Questions?