Ares V: New Opportunities for Scientific Payloads

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1.0 Executive Summary

What if scientists and payload planners had access to three to five times the volume and five to nine times the mass provided by today's launch vehicles? This simple question can lead to numerous exciting possibilities, all involving NASA's new Ares V cargo launch vehicle now on the drawing board.

Multiple scientific fields and payload designers have that opportunity with the Ares V cargo launch vehicle, being developed at NASA as the heavy-lift component of the U.S. Space Exploration Policy. When the Ares V begins flying late next decade, its capabilities will significantly exceed the 1960s-era Saturn V or the current Space Shuttle, while it benefits from their engineering, manufacturing, and infrastructure heritage. It will send more crew and cargo to more places on the lunar surface than Apollo and provide ongoing support to a permanent lunar outpost. Moreover, it will restore a strategic heavy-lift U.S. asset, which can support human and robotic exploration and scientific ventures for decades to come.

Assessment of astronomy payload requirements since Spring 2008 has indicated that Ares V has the potential to support a range of payloads and missions. Some of these missions were impossible in the absence of Ares V's capabilities. Collaborative design/architecture inputs, exchanges, and analyses have already begun between scientists and payload developers. A 2008 study by a National Research Council (NRC) panel, as well as analyses presented by astronomers and planetary scientists at two weekend conferences in 2008, support the position that Ares V has benefit to a broad range of planetary and astronomy missions. This early dialogue with Ares V engineers is permitting the greatest opportunity for payload/transportation/mission synergy and the least financial impact to Ares V development. In addition, independent analyses suggest that Ares V has the opportunity to enable more cost-effective mission design.

2.0 Ares V Overview

Ares V currently is early in the requirements formulation stage of development pending a planned authority to proceed (ATP) from NASA in late 2010. Most of the work to date has been focused on refining the vehicle design through a variety of internal studies. However, Ares V is designed to share many components with the Ares I crew launch vehicle (CLV), which is rapidly progressing from design to early fabrication and testing for its first test flight in 2009 and initial operating capability no later than 2015. The Ares V is being designed, developed, and funded by NASA's Exploration Systems Mission Directorate (ESMD), but will also be available as a national asset for exploration, science, and other nationally important missions.

The Ares V is part of a NASA exploration architecture that includes the Ares I, Orion crew exploration vehicle (CEV), and Altair lunar lander, shown in Figure 1.

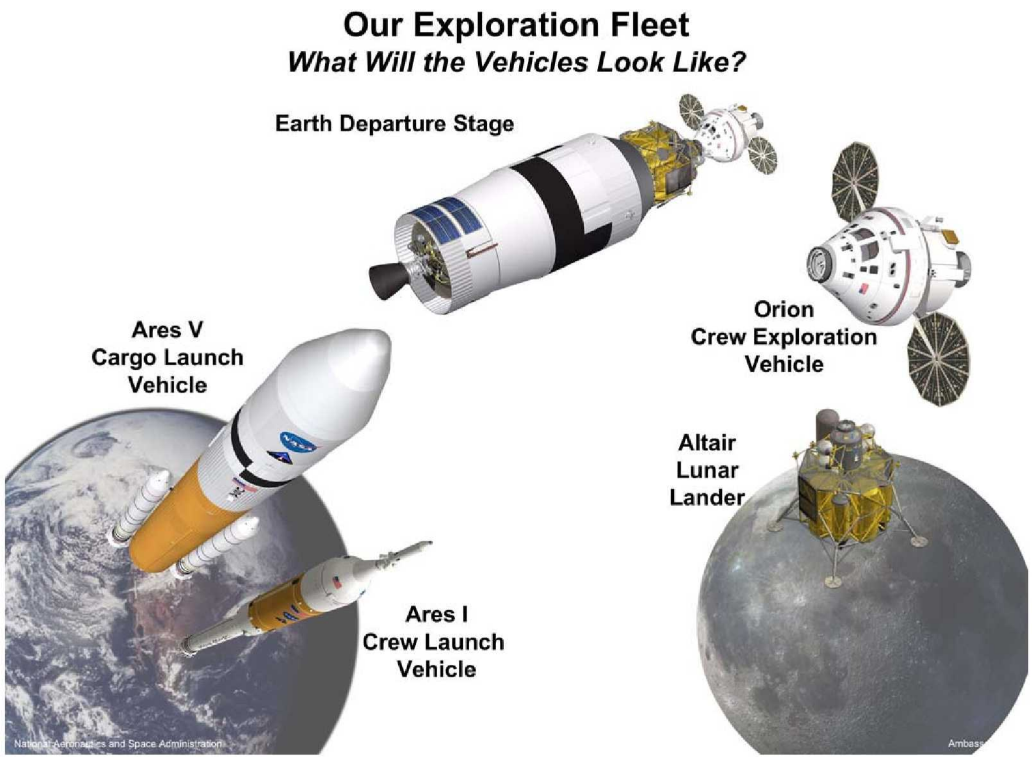

Figure 1. Main elements of NASA's Constellation architecture for future exploration.

The Ares V is designed to loft upper stages and/or cargo, such as the Altair lander, into low Earth orbit (LEO). The Ares I is designed to put Orion into LEO with a crew of up to six for rendezvous with the International Space Station (ISS) or a crew of four for rendezvous with the Ares V Earth departure stage for journeys to the Moon.

The mission and configuration of the Ares V are shaped by several broad goals that emerged from the Exploration Systems Architecture Study (ESAS), prompted in part by the recommendations of the Columbia Accident Investigation Board (CAIB). In developing a successor to the Space Shuttle fleet, ESAS separated crew and cargo transportation, putting crew on the smaller Ares I, and placing cargo on the larger Ares V. Both are designed to be safer, more reliable, and more efficient than the Space Shuttle fleet and its associated infrastructure.

Various vehicle and architecture studies sought to minimize development and operations costs and improve safety and reliability by drawing on heritage hardware and on the experience accumulated in half a century of spaceflight. NASA also sought to minimize development and operations costs by using common elements for both the Ares I and Ares V. Reviewing the science potential of the Constellation system in a report titled, *Launching Science: Science Opportunities Provided by NASA's Constellation System*, the National Research Council noted "Given the use of hardware and systems being developed for Ares I, the development risks of the Ares V are significantly reduced."[1]

As a result, the Ares I first stage and Ares V boosters are derived from the Space Shuttle boosters. The J-2X upper stage engine employed by both Ares vehicles is an evolved version of the

J-2 used on the Saturn I and Saturn V rockets. The RS-68B engine on the Ares V core stage is an upgraded version of the engine now used on the Delta IV rocket. That commonality is illustrated in Figure 2, including the current Ares V Point-of-Departure (POD) concept.

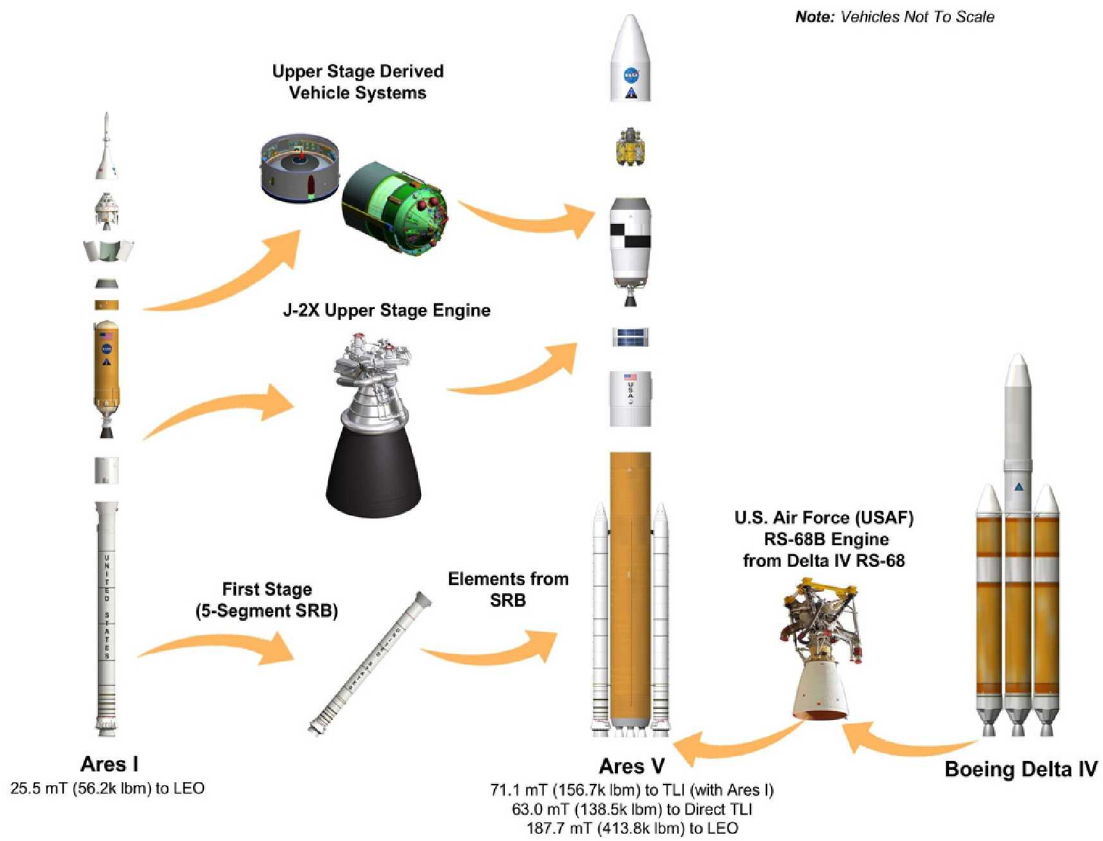

Figure 2. Heritage hardware and commonality between Ares vehicles remain key goals.

3.0 Ares V Reference Configuration

While retaining the goals of heritage hardware and commonality, the Ares V configuration continues to be refined through a series of internal trades. The current reference configuration (LV 51.00.48) was recommended by the Ares Projects and approved by the Constellation Program during the Lunar Capabilities Concept Review (LCCR) June 2008.

The reference configuration defines the Ares V as 381 feet (116m) tall with a gross lift-off mass (GLOM) of 8.1 million pounds (3,704.5 mT). Its first stage will generate 11 million pounds of sea-level liftoff thrust. It will be capable of launching 413,800 pounds (187.7 mT) to LEO, 138,500 pounds (63 mT) direct to the Moon or 156,700 pounds (71.1 mT) in its dual-launch architecture role with Ares I. It could also launch 123,100 pounds (55.8 mT) to Sun-Earth L2. Details of the current Ares V Point-of-Departure configuration are shown in Figure 3.

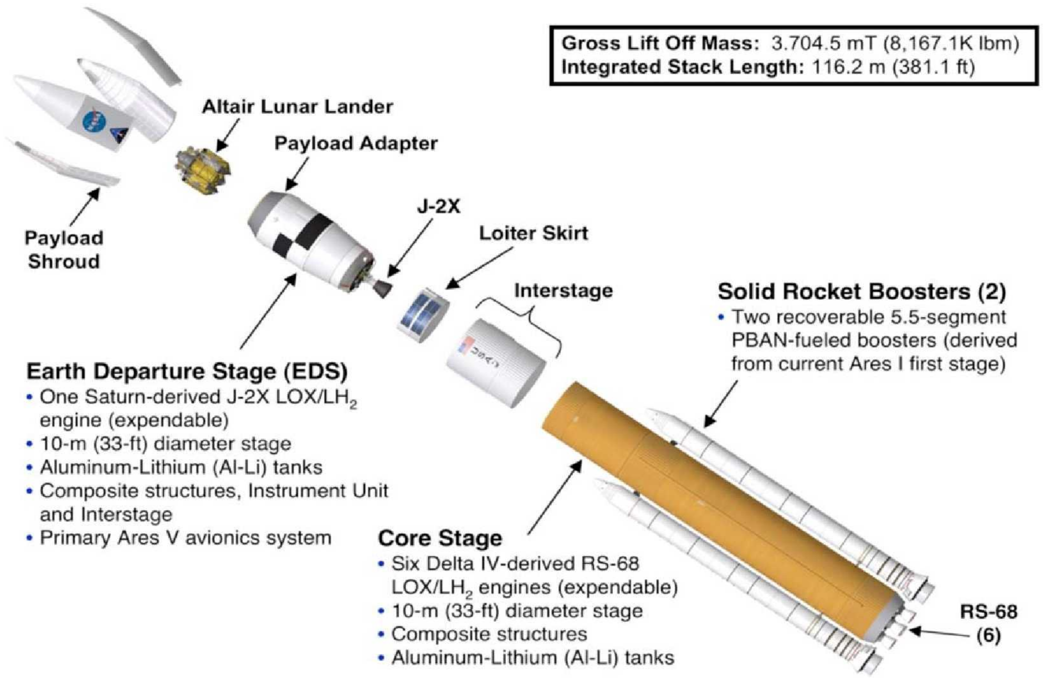

Figure 3. Expanded view of Ares V major components.

This configuration is undergoing refinement to provide the performance margin desired to accommodate potential growth of the other Constellation elements and operational realities. It serves as the basis of industry proposals solicited by NASA in January 2009 and submitted in February 2009. This phase covers concept definition and requirements development. The overall Ares V development schedule is shown in Figure 4 below.

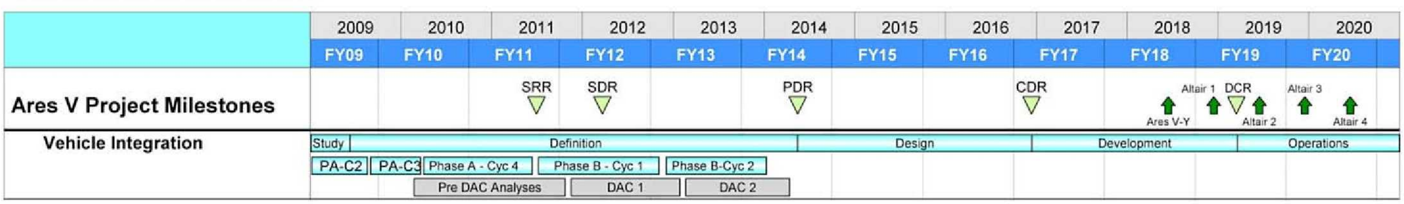

Figure 4. Ares V development schedule.

4.0 Changing the Paradigm for Future Scientific Payloads

The availability of Ares V will change substantially the opportunities for astronomy and solar system science. Unique aspects of the Ares V include its dramatically larger payload capability (mass and volume) over existing launch vehicles. The following analysis was based on pre-LCCR configuration (LV 51.00.39).

Figure 5 shows Ares V payload mass (metric tons) to LEO as a function of orbit altitude and inclination angle. The higher the orbit or greater the inclination angle, the less mass can be launched.

This data is for the conceptual design preceding the current reference design.

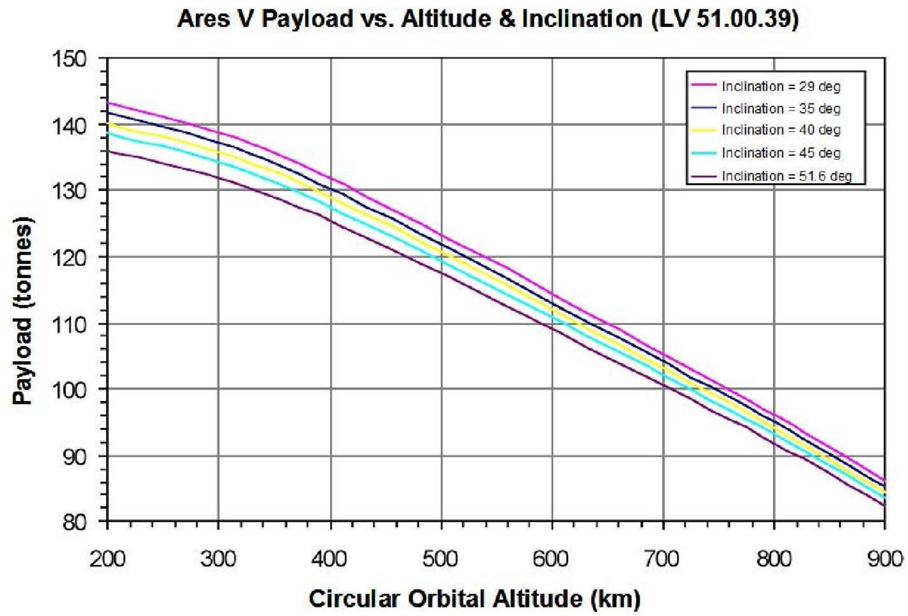

Figure 5. Ares V payload mass vs. altitude and inclination.

Figure 6 shows potential capability for science missions. Ares V, alone or with a Centaur Upper Stage, can accelerate larger payloads to large C3 energy values, thus enabling and enhancing deep space planetary missions. For example, preliminary performance assessments indicate that an Ares V could deliver a Mars sample return mission payload approximately five times greater than the most capable current vehicles.

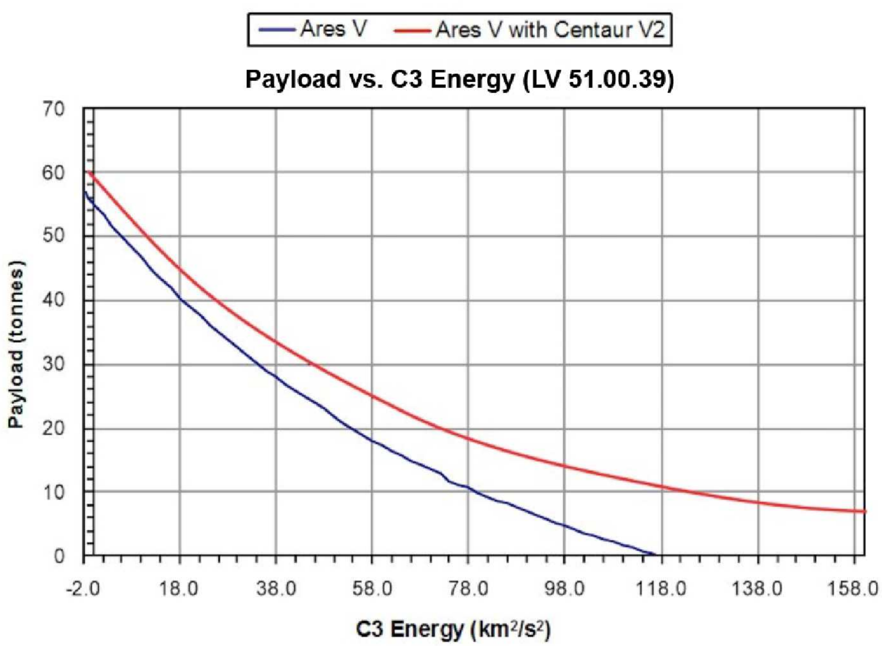

Figure 6. Ares V payload vs. C3 energy

NASA's Ames Research Center sponsored two weekend workshops in 2008 – one each on astronomy and solar system science – which allowed senior Ares V managers and the science community to talk directly, frankly, and in detail about the potential applications and challenges of extending Ares V's uses beyond its lunar mission. Because of those briefings and breakout sessions, unusual at this early stage in a vehicle development program, the Ares V design team is reviewing key issues raised in those forums.

The Workshop Report on Astronomy Enabled by Ares V concluded, "Larger fairing and lift capabilities of the Ares V open up new design concepts, e.g., large monolithic mirrors that reduce the complexity and have little risk of development. The larger-aperture telescopes that can be launched on an Ares V offer much higher sensitivity and spatial resolution than telescopes that can be launched with current launch vehicles. This is particularly important for studies of the early universe and for imaging exo-solar planets."[2] In addition, the report on the solar system science conference included similar remarks.[3] Another key point to come from the workshops is that Ares V allows the addition of mass – but not necessarily dollars – to planetary missions. Examples of "cheap mass" include increased fuel for propulsive maneuvers, radiation shielding, and redundant features.

In its "Launching Science…" report, the NRC echoed comments from the Ames conference in recognizing Ares V's possibilities: "NASA should conduct a comprehensive systems engineering-based analysis to assess the possibility that the relaxation of weight and volume constraints enabled by Ares V for some space science missions might make feasible significantly different approach to science mission design, development, assembly, integration, and testing, <u>resulting in a relative decrease in the cost of space science missions.</u>" [Emphasis added.]

<u>Payload Shroud Volume</u>

The Ares V reference configuration payload shroud is shown in Figure 7 below. This is the current configuration to enable the Constellation lunar mission.

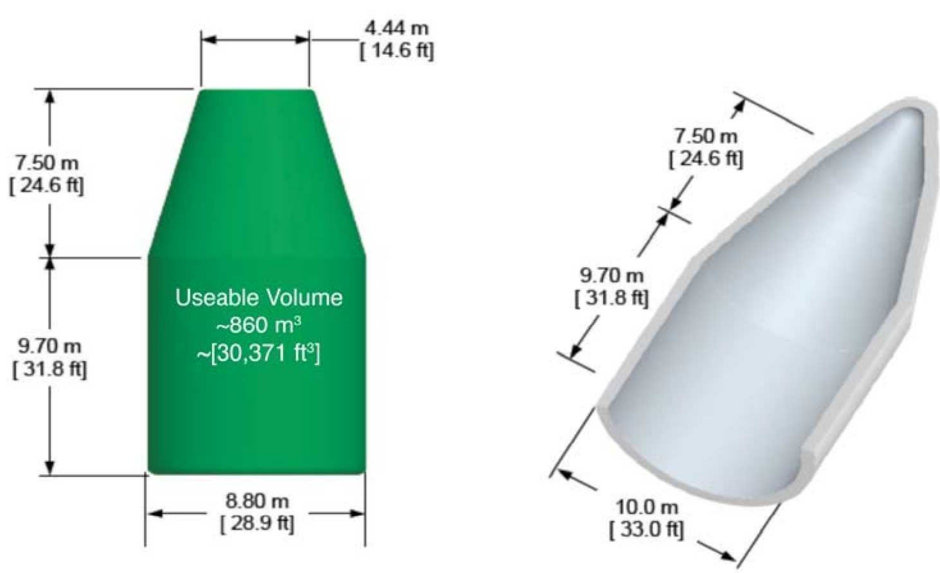

Figure 7. Ares V baseline shroud dimensions.

Another unique aspect of the Ares V rocket is the large 8.8-m interior diameter of its fairing. This enables the launch of very large monolithic mirrors, arrays of precision flying mirrors, or extremely large deployable telescopes. Active trades are under way to refine this shroud design.

A larger hypothetical shroud for encapsulating larger payloads is shown in Figure 8 below. The height of this shroud is currently limited by the height of the Vehicle Assembly Building at Kennedy Space Center.

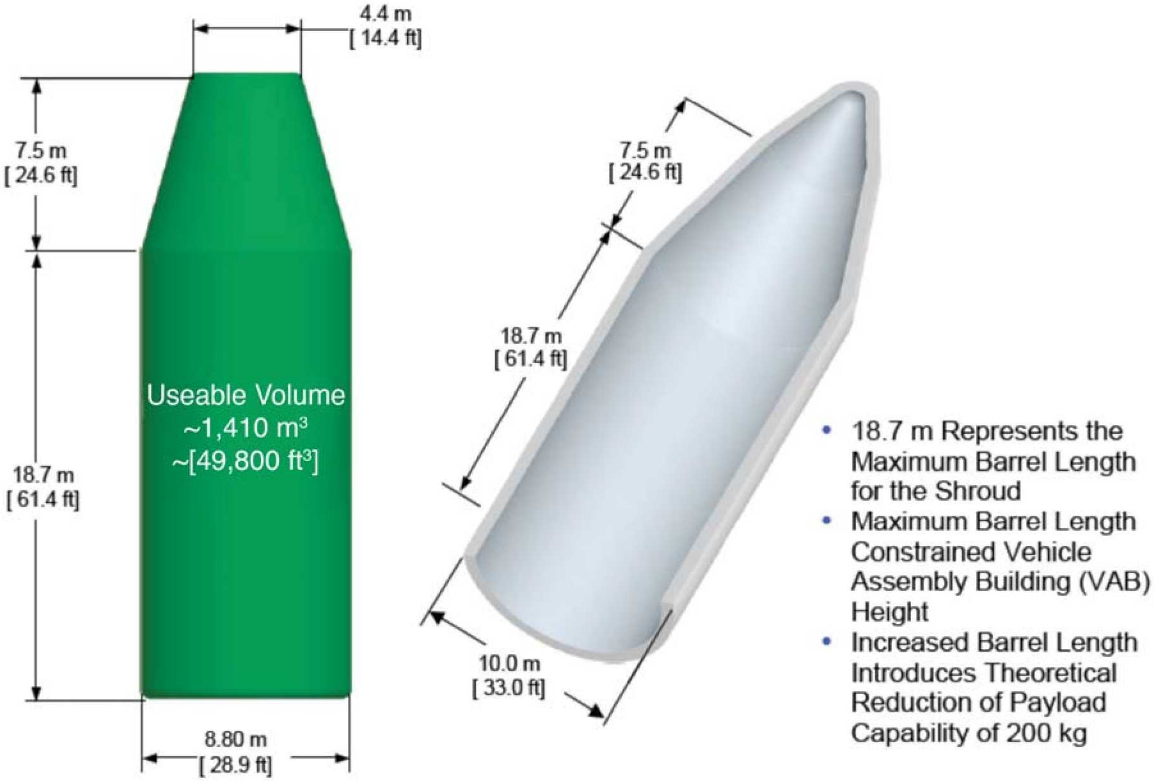

Figure 8. Hypothetical extended Ares V shroud dimensions and design issues.

As shown in Figure 9, the Ares V can deliver tremendous payloads to a wide variety of orbital parameters. Based on the pre-LCCR analysis (LV 51.00.39), the Ares V can deliver 56.5 metric tons to a Sun-Earth L2 transfer orbit and 57 metric tons to an Earth-Moon L2 transfer orbit. It can also carry approximately 69.5 metric tons to geosynchronous transfer orbit (GTO) and 35 metric tons to geosynchronous orbit (GEO). This is approximately 6 times that of any currently manufactured launch vehicle. Payloads for additional transfer orbits are also shown. Performance is expected to improve for the current concept (LV 51.00.48) when the performance analysis is completed before the end of June 2009.

Among the ground rules assumptions for these calculations were: no gravity assists, interplanetary trip times based on Hohmann transfers, payload mass estimates comprise spacecraft, payload adapter, and mission peculiar hardware, and a two-engine Centaur for kick stage. The payloads shown for the extended shroud as shown in Figure 8 are a conceptual exercise. Only the POD shroud is included in the design baseline.

Mission Profile	Target	Constellation POD Shroud		Extended Shroud	
		Payload (lbm)	Payload (mt)	Payload (lbm)	Payload (mt)
1) Sun-Earth L2 Transfer Orbit Injection	C3 of -0.7 km^2/s^2	124.000	56.5	123,000	56
2) Earth-Moon L2 Transfer Orbit Injection	C3 of -1.7 km^2/s^2	126,000	57.0	125,000	57
3) GTO Injection	Transfer DV 8,200 ft/s	153,000	69.5	152,000	69
4) GEO	Transfer DV 14,100 ft/s	77,000	35	76,000	34.5
5) LEO (@29° inclina-tion)	241 x 241 km	315,000	143	313,000	142
6) Cargo Lunar Outpost (TLI Direct), Reference	C3 of -1.8 km^2/s^2	126,000	57	125,000	57
7) Mars Cargo (TMI Direct)	C3 of 9 km^2/s^2	106,000	48	105,000	48

*based on LV 51.00.39

Figure 9. Ares V performance for selected missions.

This potentially opens up direct missions to the outer planets that are currently only achievable using indirect flights with gravity assist trajectories. An Ares V with an upper stage could perform these missions using direct flights with shorter interplanetary transfer times, which would enable extensive in-situ investigations and potentially sample return.

As an example, a preliminary NASA Science Mission Directorate (SMD) study is under way to study the capability of the current LV 51.00.48 reference design. Results to date indicate an increase approximately 20,000 kg more – or approximately 161,000 kg – to LEO. The reference configuration also has the potential of sending approximately 65,000 kg to a Sun-Earth L2. The study will be completed in the summer of 2009.

5.0 Is There Value in Simplicity?

A major concern in considering the use of heavy-lift launch vehicles is the affordability of the payloads: a very large capacity of a fairing would enable very large and/or massive scientific payloads. If cost scales with mass, one can easily imagine Ares V payloads that would not be affordable with today's science budgets. The trade-offs between simplicity and complexity have already been a major topic in initial discussions between Ares V and the science community.

By having very significantly increased available payload mass and volume, Ares V enables a new paradigm, namely the potential ability to reduce risk, cost and development time by designing for simplicity. Ares V has the throw capability to solve payload design problems by brute force alone. For example, payload developers concerned about acoustic environments during launch and ascent might choose to attenuate acoustic loads with 10,000 pounds of ballast. This may be only one of many new "knobs" payload designers may discover and "turn" to take full advantage of Ares V's capabilities.

This, in turn, requires rethinking the ground processing and testing infrastructure for simple and rugged, but also for larger and heavier spacecraft, apertures, and components. Early technical exchanges with the payload community have considered such options (e.g., CP-2008-214588).[2]

Ares V offers a crosscutting solution to a wide range of payloads if the science community is willing to assess an alternative to the existing approach that has driven them to employ complexity to solve current launch vehicle mass and volume constraints. Payload designers stand to gain greater scientific "bang for their buck" and, conversely, less undesirable "bang" in the form of mission-jeopardizing risk, by using Ares V's mass and volume capabilities as margin.

One NASA mission provides anecdotal evidence that large mass and volume margins can enable significant cost savings. The Earth Radiation Budget Satellite (ERBS) was a free-flying Earth observing satellite launched by the Space Shuttle in 1984. As one of the early shuttle payloads, ERBS took advantage of the large mass and volume margins provided by the shuttle to use off-the-shelf components and robust design technologies. The result was a satellite bus cost that was 70% less on a per pound basis than an average of similar Earth observing spacecraft.

While the cost performance of a single mission should not be used to set expectations within NASA and the science community, it does illustrate that the potential exists to use large mass and volume margins to achieve cost savings if requirements are managed wisely early in the program. Two studies by The Aerospace Corporation in 2008 further suggest some inherent payload-wide design issues where Ares V capabilities could help. One notes that "use of heavy, low-cost technologies was shown to decrease costs from lightweight advanced technologies. Use of existing technology was shown to reduce development costs by 54% on a pound for pound basis."[4] The second study suggests that mass, schedule, and cost growth is common, interrelated, and significant among science payloads.[5]

While many payload cost models to date use mass to estimate cost, recent thinking notes that not all cost drivers are being addressed in existing models. Among the factors attracting more attention are "new design" and "integration complexity," a 2003 NASA paper noted.[6] These and other factors such as management, manufacturing, and funding are being combined into analyses that plot mission complexity versus cost to provide a more refined prediction of expected mission success or failure – a tool that can greatly assist the payload community. Those calculations are complex but they can be distilled into a simpler equation: simplicity equals less technical risk and higher confidence in mission success. "A clear dependence of success rate on systems complexity was identified," declared a May 2000 paper by The Aerospace Corporation.[7]

6.0 Conclusion

The Ares V payload volume is dramatically larger than any vehicle past or present. As suggested by the author, this capability, along with increased mass, offers payload developers several desirable options. Bigger/Better/Faster/Farther is always an attractive design goal to scientists with the unquenchable desire to explore beyond today's limits. Ares V allows them to do that. For those willing to explore the possibilities within the payload development cycle universe—particularly those facing limited resources—Ares V also holds the possibility of new less costly, less risky solutions for the astronomy community.

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