NASA/CP–2008-214592

Workshop Report On
Ares V Solar System Science

Authors:

Stephanie Langhoff
Chief Scientist
Ames Research Center, Moffett Field, California

Tom Spilker
Mission Architect, Planetary Scientist
Jet Propulsion Laboratory, Pasadena, California

Gary Martin
Director, New Ventures and Communications Directorate
Ames Research Center, Moffett Field, California

Greg Sullivan
Consultant, GPS Solutions
Reno, Nevada

Report of a workshop
sponsored by and held at
NASA Ames Research Center
Moffett Field, California
on August 16-17, 2008

December 2008

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at (301) 621-0134

- Telephone the NASA Access Help Desk at (301) 621-0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/CP–2008-214592

Workshop Report On
Ares V Solar System Science

Authors:

Stephanie Langhoff
Chief Scientist
Ames Research Center, Moffett Field, California

Tom Spilker
Mission Architect, Planetary Scientist
Jet Propulsion Laboratory, Pasadena, California

Gary Martin
Director, New Ventures and Communications Directorate
Ames Research Center, Moffett Field, California

Greg Sullivan
Consultant, GPS Solutions
Reno, Nevada

Report of a workshop
sponsored by and held at
NASA Ames Research Center
Moffett Field, California
on August 16-17, 2008

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

December 2008

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Table of Contents

Executive Summary

On August 16th and 17th, 2008, NASA Ames Research Center hosted a two-day weekend workshop entitled "Ares V Solar System Science." The primary goal of the workshop was to begin the process of bringing the Ares V designers together with senior representatives of the planetary science community to discuss the feasibility of using the Ares V heavy-lift launch vehicle, a major element in NASA's Constellation Program, to launch demanding missions to explore the solar system. This workshop was a follow-on to a previous very successful workshop looking at astronomy missions that might be enabled by an Ares V.

It was very clear from the outset that the availability of an Ares V changes the paradigm of what can be done in planetary science. Preliminary performance estimates indicate that an Ares V could deliver approximately five times the payload mass to Mars compared with the most capable existing vehicles such as the Delta IV Heavy. The Ares V is also capable of much larger C_3s (hyperbolic excess speed over escape, squared). 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 enables extensive in situ investigations and potentially sample return options.

A number of innovative mission concepts were presented at the workshop. One key observation was that the large payload capacity of the Ares V permits the addition of "cheap", but useful mass. Examples include extra fuel for propulsive maneuvers, shielding to protect from harsh radiation, drill strings and casings for drilling, and redundancy. Sample return missions benefit from all aspects of the Ares V performance. For example, the Ares V could potentially enable sample return from Jupiter's moon Europa, because it would have the payload capacity to provide shielding for a lander on the surface, and sufficient fuel for propulsive maneuvers out of the gravitational well of Jupiter. At Enceladus, a small active moon of Saturn, the Ares V could carry the fuel needed to slow down for sample capture from the plumes on Enceladus, or create an artificial plume on either Europa or Enceladus by firing a copper projectile at the surface.

Human exploration mission concepts were presented that would use other Constellation assets in addition to the Ares V. One mission concept proposed that humans explore the surface of Venus through telepresence robots while the humans reside inside the spacecraft in orbit around Venus. The human mission is two years, while the surface robotic mission is designed to last 17 years. While this mission concept requires two Ares V launches and technology maturation of Stirling-cycle power and cooling, only an Ares V would have the launch payload to put multiple rovers on the surface of Venus.

The workshop also touched on Earth Science and Heliophysics missions that could benefit from an Ares V. For Earth science the Ares V would be most useful for placing large observatories either in geostationary orbit (GEO) or at the Sun-Earth Lagrange points (L1 and L2). For example, in GEO large aperture (>10 m) microwave sounders could provide useful spatial resolutions of temperature and rain measurements for severe weather monitoring/prediction, and large synthetic aperture radars could be used for surface wind predictions.

Heliophysics missions that explore the interaction of the outer heliosphere and local interstellar medium benefit from the large C_3 capability of the Ares V. A combination of an Ares V launch, with an upper stage powered by ion engines fueled by a high-specific-energy radioisotope source, and gravity assist at Jupiter, could reach escape speeds from the solar system of ~10 Astronomical Units (AU) per year, a factor of about three larger than the Voyager spacecraft.

Goals of the workshop included identifying payload requirements, technology maturation needs, and infrastructure considerations for planetary missions. For example, late payload access is needed both for nuclear powered payloads and for fueling of a Centaur or other upper stage. Technology maturation needs include drill systems for Mars and Europa, high temperature electronics and cryo-coolers for Venus, and aerocapture with large aeroshells. Examples of infrastructure requirements include flight development and integration facilities and containment and curation facilities.

In summary, the Ares V changes the paradigm of what can be launched, because its launch performance (C_3 versus payload) is far greater than that of any current vehicle. In addition, its dramatically larger launch fairing enables launching large, multi-element systems, greater science instrument mass fraction, larger electrical power supplies, and more mass for shielding and for lower-complexity engineering solutions. This translates into an earlier return on science, a reduction in mission times, and greater flexibility for extended science missions. It is particularly enabling for sample return, which takes advantage of all of the Ares V capabilities. We encourage the science community to think big, because an Ares V expands the envelope of what can be done in planetary science.

Workshop Report On Ares V Solar System Science

Stephanie Langhoff[1], Tom Spilker[2], Gary Martin[1], and Greg Sullivan[3]

Ames Research Center

I. Introduction

A workshop entitled "Ares V Solar System Science" was held at Ames Research Center on the weekend of 16-17 August 2008. This workshop is part of a series of informal weekend workshops initiated and hosted by the Ames Center Director, S. Pete Worden. The organizing committee included Stephanie Langhoff (Chair), Gary Martin, and Jennifer Heldmann of Ames Research Center; Greg Sullivan, Phil Stahl, and Kenneth Morris of Marshall Space Flight Center; Harley Thronson and Gordon Chin of Goddard Space Flight Center; and Tom Spilker of the Jet Propulsion Laboratory. The workshop agenda was structured to bring together the Ares V designers and the science and engineering communities who have a common interest in launching large solar system science missions. Forty-nine people representing government, industry, and academia attended (see list of attendees). This workshop directly addresses recommendation 7-1 in the Aldridge report (ref. 1), which recommends that "NASA seek routine input from the scientific community on exploration architectures to ensure that maximum use is made of existing assets and emerging capabilities."

The workshop blended three major themes: (1) How can elements of the Constellation program, and specifically, the planned Ares V heavy-launch vehicle, benefit the planetary community by enabling the launch of large planetary payloads that cannot be launched on existing vehicles, and how can the capabilities of an Ares V allow the planetary community to redesign missions to achieve lower risk, and perhaps lower cost on these missions? (2) What are some of the planetary missions that either can be significantly enhanced or enabled by an Ares V launch vehicle? What constraints do these mission concepts place on the payload environment of the Ares V? (3) What technology challenges need to be addressed for launching large planetary payloads? Presentations varied in length from 15-40 minutes. Ample time was provided for discussion.

The final afternoon was devoted to interactive discussions, organized around two specific questions: (1) How does Ares V enhance or enable planetary sample return? and (2) Payload development and accommodation: What are the major technological and environmental issues?

The program ended with a discussion of research priorities and follow-on actions.

---

[1]NASA Ames Research Center, Moffett Field, California
[2]Jet Propulsion Laboratory, Pasadena, California
[3]GPS Solutions, Reno, Nevada

II. Overview of NASA's Planetary Division Objectives

James Green, Director of NASA's Planetary Science Division, began the workshop with an overview of the planetary division's objectives. NASA's planetary science program mission is to advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space. He began by showing the timeline for planetary missions out to 2020. He first focused on the Discovery Program, which is designed to promote lower cost (<$425 million) highly focused planetary science investigations. This program has achieved a number of firsts, such as first surface rover to explore another planet (Mars Pathfinder), first to orbit and land on an asteroid (NEAR), first to collect particles from a comet and return them to Earth (Stardust), and the first purely science mission powered by ion propulsion (Dawn to the main belt asteroids Vesta and Ceres). Green also briefly discussed the Discovery and Scout Mission Capabilities Expansion (DSMCE) program that solicits mission concepts for low-cost planetary missions that require a nuclear power source such as the Advanced Stirling Radioisotope Generator (ASRG).

The planetary division's approach to Mars exploration has three aspects: (1) an orbital and airborne reconnaissance effort; (2) in-situ (surface) experiments and reconnaissance for ground truthing and subsurface access; and (3) sample return of rock and soil samples. Building on the success of the Mars rovers Spirit and Opportunity and the Mars Reconnaissance Orbiter (MRO), follow-on NASA missions include the Mars Science Lab and Mars Atmosphere and Volatile Evolution mission with sample return estimated for about 2020.

Dr. Green next discussed the New Frontiers Program, which was initiated in 2004 to support medium-sized planetary missions. The first New Frontiers mission was New Horizons that was launched in 2006 to study Pluto and the Kuiper Belt. The second mission in this class is the Juno mission that is being built for launch in 2011. The call for proposals is expected this fall for the 3rd New Frontiers Mission opportunity.

He ended by discussing a few of the missions that were being considered for the future. These include a NASA Jupiter Europa Orbiter concept that could be a standalone spacecraft or be designed to operate synergistically with the European Space Agency's (ESA) Jupiter Ganymede Orbiter. Another mission concept is the Titan Core mission that is being designed to study Titan, Enceladus, and Saturn. This would be an international mission with ESA providing a Montgolfiere balloon and a lander. The balloon would circumnavigate Titan at about 10 km altitude. The lander (or buoy) is currently targeted for Kraken Mare, a sea in the north polar region. Taking advantage of coordinated multi-agency missions and the development and use of in-space propulsion and radioisotope power systems are seen as emerging trends for the planetary division. In addition, heavy-lift systems, such as the Ares V, will help enable carrying out missions such as sample return more effectively and with less risk.

III. Ares V Capability and Constellation Overview

III.1 Constellation Overview

John Horack presented an overview of the Constellation Program. The discussion here attempts to capture some of the key points made in his presentation, and to set the stage for the science presentations that follow. More in depth and authoritative accounts of the rapidly unfolding Constellation and Ares programs exist on the internet (ref. 2).

As of May 2008, NASA's mission contains six major elements: (1) Safely fly the Space Shuttle until 2010; (2) Complete the International Space Station; (3) Develop a balanced program of science, exploration, and aeronautics; (4) Develop and fly the Orion Crew Exploration Vehicle; (5) Land on the Moon no later than 2020; and (6) Promote international and commercial participation in exploration. A key reason for making the Moon a key focus of the exploration initiative is that it can be reached with existing or evolved launch systems. At the same time, it has been increasingly recognized that such transport systems can straightforwardly access other interesting destinations such as Geosynchronous Earth Orbit (GEO), the Sun-Earth and Earth-Moon Lagrange (libration) points, and some asteroids. Lunar missions also help retire risk for future planetary missions by re-acquiring human exploration experience and testing of the Constellation architecture. Unlike the Apollo program that was constrained to the equatorial regions, the Constellation architecture will enable landing anywhere on the moon.

One of the cornerstones in the Ares program is to build on a foundation of proven technologies to reduce risk. The Ares vehicles are compared with the Space Shuttle and the Saturn V in figure 1. The Ares I, which is under development now, will have a payload capacity of 25.5 metric tons to Low Earth Orbit (LEO), comparable to that of the Shuttle. For comparison, the Ares V is estimated to have a payload capacity of approximately 187.7 metric tons to LEO, considerably larger than the Saturn V (118.8 mT). The Ares V will, therefore, provide lift capability that exceeds all previous vehicles and will clearly open up new opportunities for science and human exploration.

Briefly, the Ares I is being designed to carry the astronauts in the Orion Crew Exploration Vehicle (CEV) that sits just behind the crew escape module atop the stack. The upper stage uses an expendable engine derived from the Saturn J-2 that uses LOX/LH_2 propellant, and is mostly based on proven technologies. The first stage engine on the Ares I is derived from the current Shuttle Reusable Solid Rocket Motor Booster (RSRM/B). It uses the same propellant, cases and joints, booster deceleration motors, aft skirt and thrust vector control, and tumble motors as the Shuttle. The use of heritage parts when feasible combined with the use of modern electronics and composite materials should produce a highly dependable solid rocket booster, while reducing complexity, risk, and cost. The Ares I is currently undergoing testing and vehicle integration. The Ares I-X test flight scheduled for next year will collect key data to further refine the Ares I design.

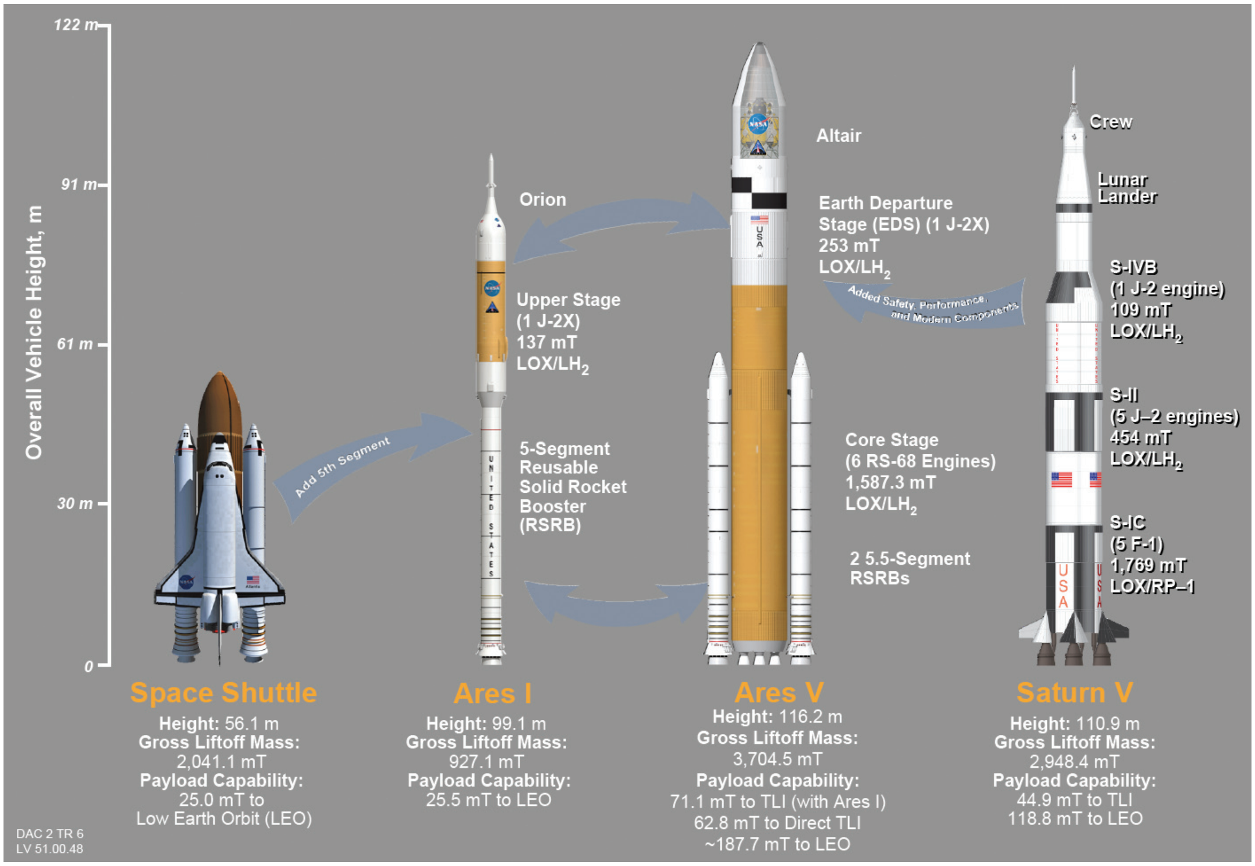

Figure 1. Building on a foundation of proven technologies—Launch vehicle comparisons.

Horack also discussed the status of the Orion Crew Exploration Vehicle and the Altair lunar lander. The Orion Crew Module has about 80% more volume than Apollo. It also has a sophisticated launch abort system that could be activated in case of a launch failure. The Altair lunar lander is being designed to transport a crew of four to and from the lunar surface. Flown in a robotic mode without a crew, it can deliver approximately 16 metric tons of cargo.

The elements in the Ares V heavy-lift vehicle are shown in figure 2. The payload fairing is being designed to carry the Altair lunar lander. One of the primary focuses of the workshop was to determine what demands launching large planetary payloads might place on the design of the fairing. There may be some design flexibility in the fairing as long as it carries out its principal mission of transporting Altair to the lunar surface. Other elements of the Ares V shown in figure 2 include the Earth Departure Stage (EDS), a loiter skirt, an interstage, and then the core stage that is powered by six Delta IV derived RS-68 LOX/LH_2 engines and two solid rocket boosters that have been lengthened to 5.5 segments. In summary, the Ares program is using previous lessons learned and proven technologies to minimize cost, technical and schedule risks. First test flights of the Ares I are scheduled to occur in April 2009, and the first test flight of Ares V is planned for 2017.

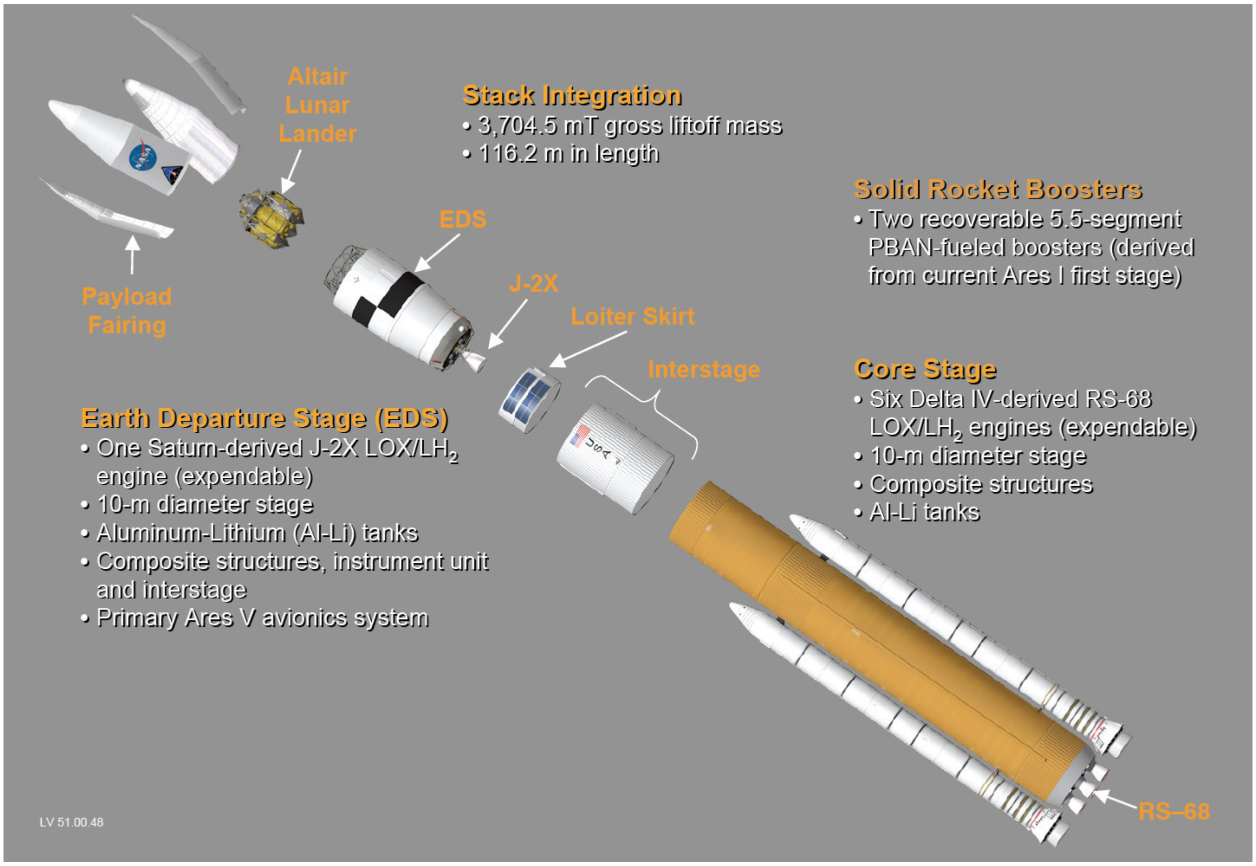

Figure 2. Ares V elements.

III.2 Overview and Performance of the Ares V

Phil Sumrall, the Advanced Planning Manager for the Ares Projects Office, gave a two-part presentation on Ares V, providing first a mission and vehicle overview, and then a description of performance. The Ares V, which is primarily being designed as a heavy-launch vehicle to place cargo on the Moon, is intended to have greater payload capacity to Low Earth Orbit (LEO) than all previous vehicles including the Saturn V. Sumrall discussed in detail the design concepts for all of the key elements of the Ares V including the EDS, the core stage, the notional instrument unit, the EDS J-2X engine, the SRBs, and the core stage upgraded RS-68 engines. Since this information is available on the internet (ref. 2), and is not critical as to how an Ares V could be used to launch large planetary payloads, we omit the details here.

One element of the Ares V design that is important for planetary missions is the shape and interior dimensions of the upper stage shroud. Sumrall presented a shroud shape trade study that they had done within the restriction of a 9.7-m barrel height. This barrel height is required to accommodate the current Altair lander configuration. They considered many shapes such as hemispheres, tangent ogives, blunt cones, etc., but selected the biconic shroud shown in figure 3 as their baseline. However, a leading alternative is the tangent ogive shroud, which would provide greater internal volume.

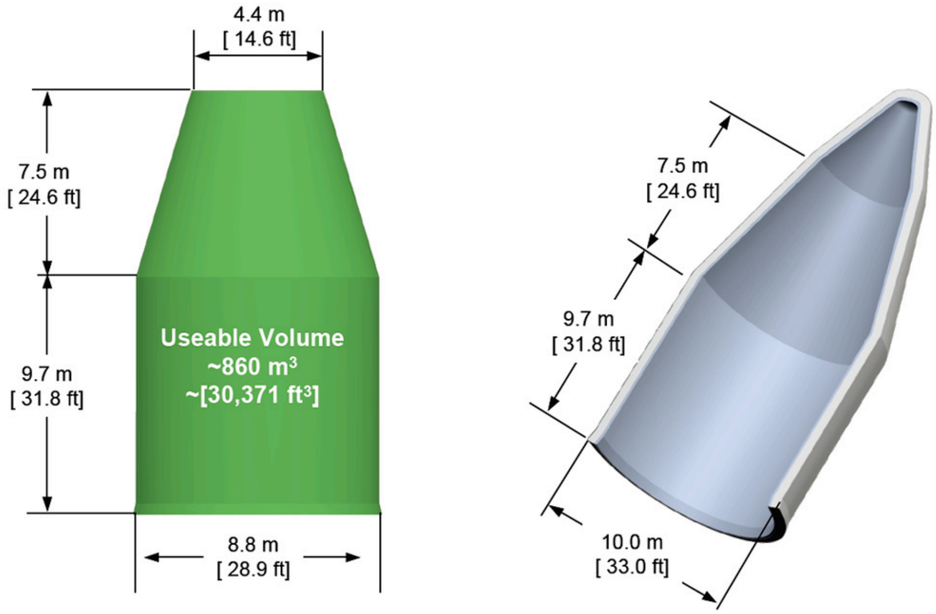

Figure 3. Current Ares V biconic shroud concept.

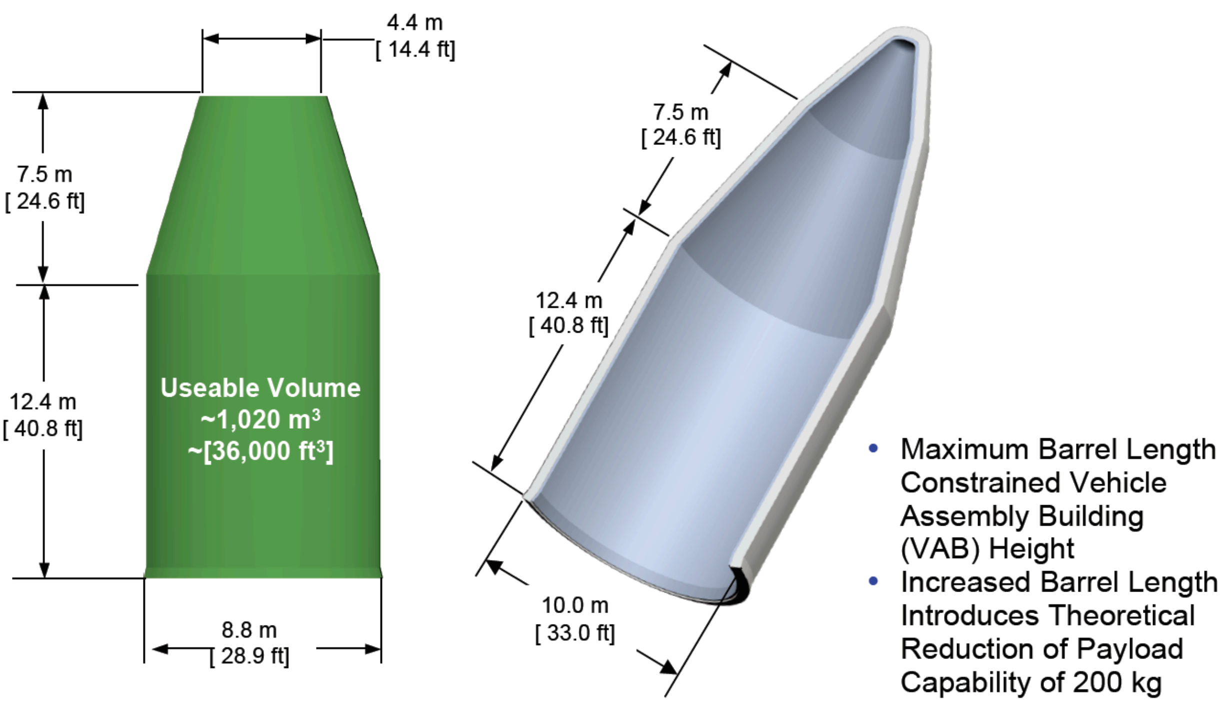

Figure 4. Notional Ares V biconic shroud for other missions.

A critical dimension is the 8.8-m diameter interior of the barrel. Shown in figure 4 is a notional Ares V shroud for other missions. The maximum length of the barrel is constrained to 12.4 m by the height of the Vehicle Assembly Building (VAB) at Kennedy Space Center. Note that the maximum length of the barrel is decreased by 6.3 m compared with that presented in the "Astronomy Enabled by Ares V" workshop report (ref. 3). The decrease results from the recent redesign of the Ares V to six RS-68 engines and to 5.5 segment SRBs. The addition in length to the SRBs results in a longer rocket and, therefore, a greater constraint on the maximum length of the shroud. These changes to the vehicle were required for the Ares V to perform its primary lunar mission with sufficient margin. This highlights the fact that the design of the Ares V is still changing with time. It is important to point out, however, that the Ares V design draws heavily from the Ares I and Delta IV rockets to minimize development costs and reduce risk (see fig. 5).

Sumrall also discussed the impressive Ares V escape velocity performance, which will be very important in reducing the travel time for planetary missions. The performance of the vehicle is illustrated in figure 6 where payload mass is plotted versus C_3, the launch velocity in excess of escape squared in km^2/s^2, using the extended shroud and vehicle performance prior to the redesign. What this performance translates to for planetary missions is discussed in the following sections.

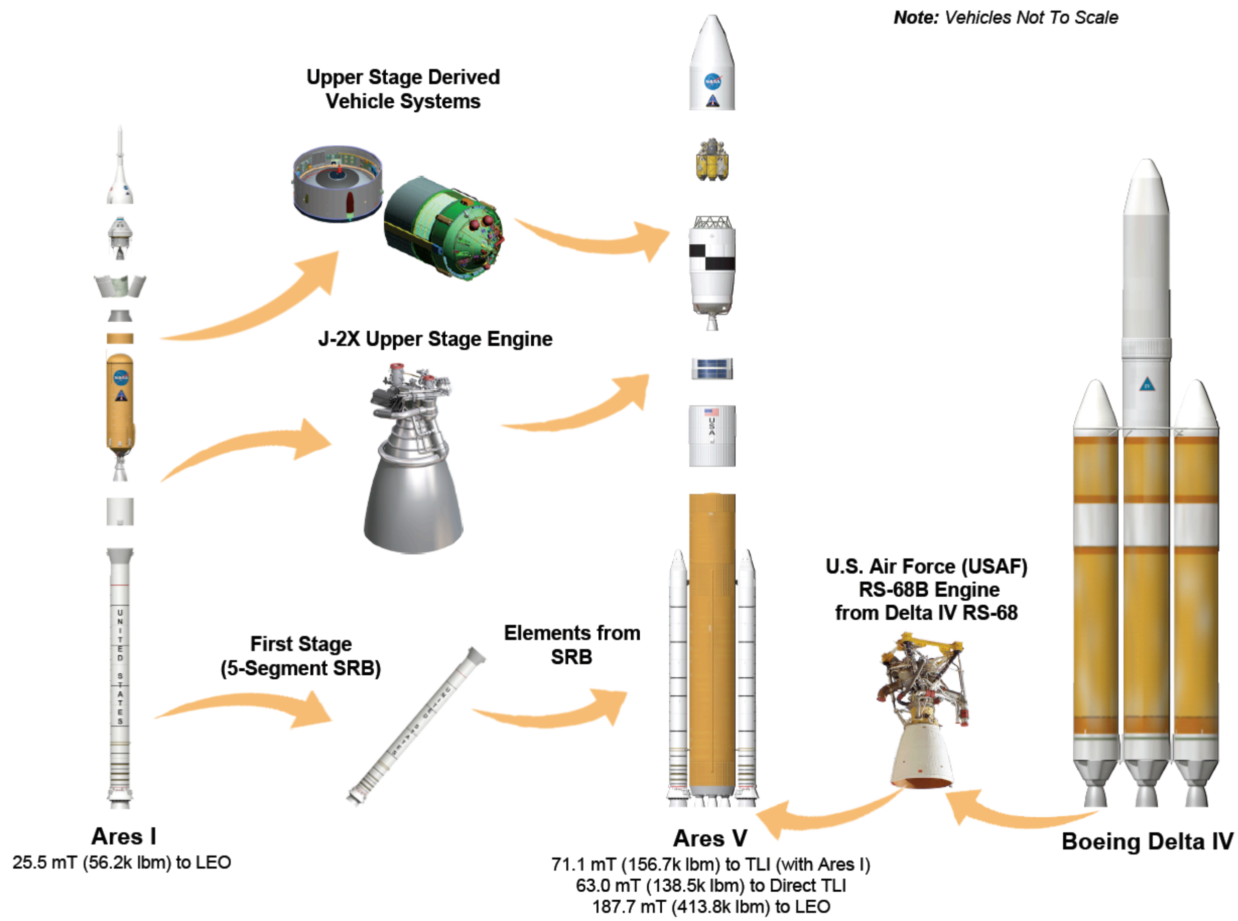

Figure 5. Ares V element heritage.

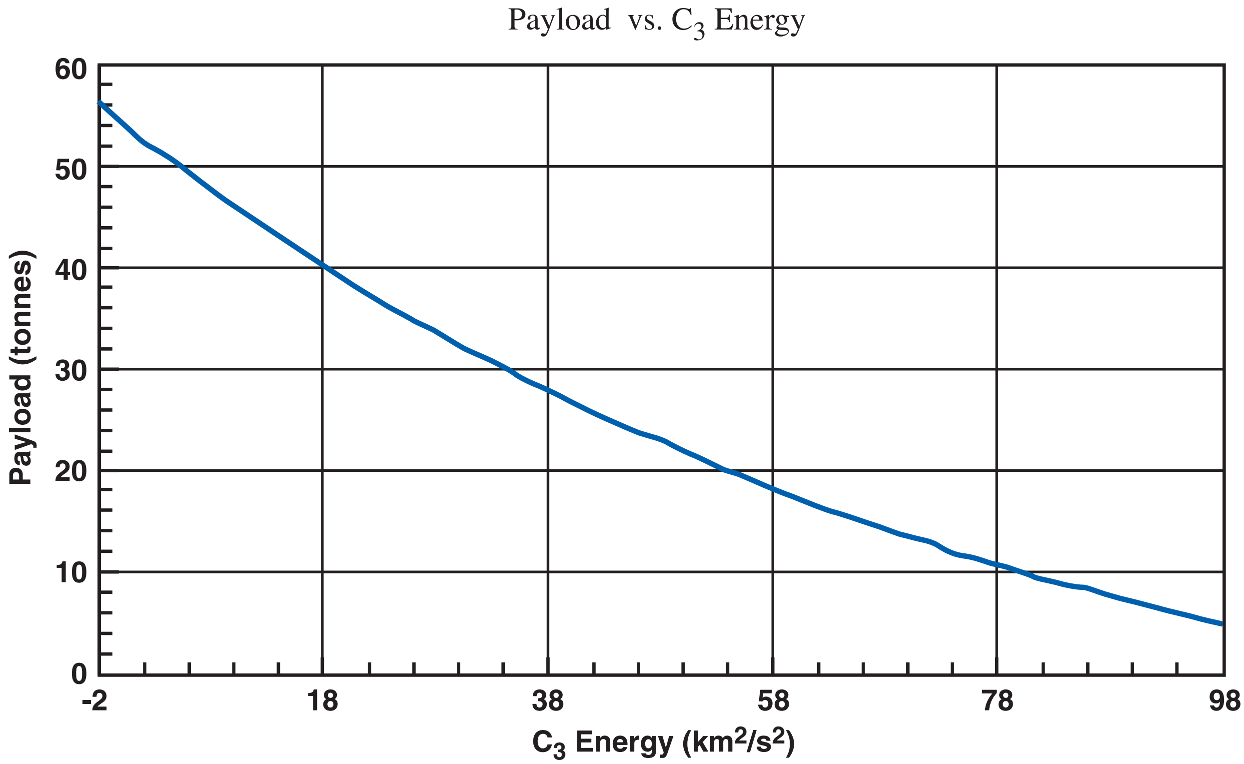

Figure 6. Ares V escape performance.

III.3 Science Operational Capabilities Enabled by Ares V Performance

To help translate the performance capabilities of the Ares V into operational capabilities relevant to planetary missions, Tom Spilker presented a paper entitled "The Value of the Ares V Launch Vehicle for Planetary Science Missions". This was, in part, a synopsis of the analysis presented in reference 4. What makes the Ares V unique is that its launch performance is far greater than that of any other heavy launch vehicle. In figure 7 we have plotted payload capacity in kilograms (kg) (1 metric ton = 1000 kg) versus C_3. Note that these are the performance curves prior to the redesign of the Ares V to 6 RS-68 engines and 5.5 segment solid rockets. The performance of the redesigned vehicle should be slightly better than that shown in figure 7. The performance of the Delta IV Heavy (represented by the magenta curve) is the current state-of-the art. The blue curve represents the predicted performance of the Ares V, and the yellow curve the performance of the Ares V with a Centaur upper stage. The stack mass limit is taken to be 54 mT (metric tons) based on the mission mass on top of the Earth Departure Stage (EDS). The inclusion of the upper stage substantially improves the C_3 performance for a given payload, but reduces the maximum payload capacity to 31 mT. The increased launch performance benefits planetary science by enabling much larger payloads for a given C_3, or for a given payload, much higher C_3s, which reduces trip times especially to the outer planets or to Mercury.

Performance curves (C_3 vs payload capacity)

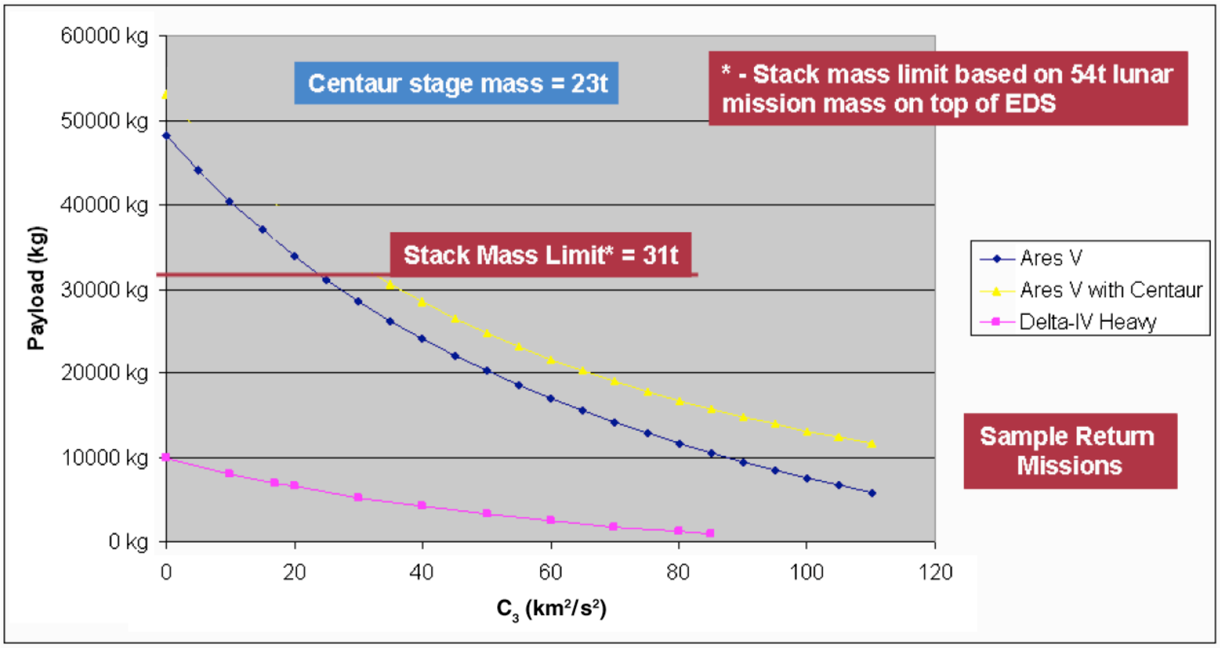

Figure 7. Ares V performance curves.

The greater launch mass of the Ares V benefits planetary science in a number of ways. Allowing, for example:

- the launch of large, complex systems such as multiple probes, orbiters, landers, etc.
- greater science instrument mass and mass fraction
- larger electric power supplies for instruments and telecom transmitters
- greater post-launch Delta-V for expanded access and access to multiple destinations
- greater mass for shielding against radiation exposure or other environmental hazards
- greater mass for lower-complexity engineering solutions, such as propulsive orbital insertion

This would benefit planetary science by providing an earlier return of science, reducing mission duration, and providing greater flexibility for single-element missions to multiple destinations. The large interior diameter of the fairing (8.8-m interior diameter) enables using large apertures for optical instruments or for aeroshells, simplifies packaging of large, complex systems, and simplifies the launch configuration of multi-element missions.

Large, complex, and/or multi-element planetary missions would all benefit from an Ares V. Examples would include long-lived surface elements at Venus or Mercury, science constellations such as multi-element missions to Saturn (see later discussion), planetary networks emplaced with a single launch, ice giant orbiters, and single flight elements orbiting multiple destinations. However, sample return missions would benefit the most from an Ares V, since they would use all aspects of the Ares V increased launch performance. Spilker illustrated the utility of Ares V for sample return by describing example benefits for missions to Mars, Venus, Mercury, and destinations in the outer solar system.

One of the purposes of the workshop was to identify key Ares V design criteria that need to be considered to avoid precluding planetary mission launches. Planetary payloads often require prelaunch flight system cleanliness (e.g., to facilitate planetary protection) and control of the vibrational, acoustical, and thermal environment before and during launch. The handling of payloads includes radioisotope power sources and heaters, and a fueled upper stage. This often requires easy and late access (while on the pad) to locations within the shroud. These issues are discussed in more detail later in the report.

IV. Planetary Mission Concepts

IV.1 Brief Overview of Potential Planetary Exploration Enabled by Ares V

Gordon Chin gave an overview of potential planetary missions that might be enabled by an Ares V. He contended that several of the flagship missions that are currently under formulation could benefit from an Ares V because of its capability to lift more complete and larger payloads and reduce travel times. Specific examples include an international Titan-Saturn mission containing three mission elements, namely an orbiter (NASA), Montgolfiere (balloon, ESA), and a probe or lander (ESA). The science goals include understanding Titan's complex chemistry, the source of the geysers on Enceladus, and characterizing the magnetospheres of Enceladus and Saturn. A second flagship mission possibility is a Europa-Jupiter system mission that could include Io, Jupiter, and Ganymede campaigns. The science goals at Europa include characterizing the extent of its subsurface ocean, determining its global surface composition and chemistry, and understanding the formation of its surface features. Other more ambitious missions include a Neptune orbiter, probe, and Triton lander, a Uranus orbiter with probe, and a Mercury sample return mission. These missions may be feasible with an Ares V, but probably not with the current heavy launch systems.

Dr. Chin concluded his talk by discussing heterodyne techniques as a means of performing high-resolution spectroscopy on planetary atmospheres. The technique is particularly applicable to the sub-millimeter spectral region, because of the numerous molecular transitions that occur at these wavelengths in planetary atmospheres. This technique has been widely used in Earth science, and has wide application in planetary science as well. For example, it could be a valuable tool for studying the runaway greenhouse effect on Venus, and for studying the super-rotating cloud layers on Venus and Titan. He discussed briefly the Vesper mission that is designed to probe the chemistry and dynamics in the Venus atmosphere using high-sensitivity heterodyne spectroscopy. A submillimeter spectrometer is also being proposed for the MARS Volcano Emission and Life Scout (MARVEL Scout) mission. MARVEL would orbit Mars in a near-polar orbit to search for near-surface water and signs of life.

IV.2 Sample Return from Europa and Enceladus Using the Ares V

Chris McKay discussed sample return missions to Europa and Enceladus. A key point in his presentation was that an Ares V allows adding mass, but not dollars, to planetary missions. Examples of "cheap mass" include fuel for propulsive maneuvers, shielding for protection against harsh radiation environments, drill strings and casings for penetrating regolith and/or ice, and redundancy, e.g., many duplicates of a small lander.

A key driver for planetary exploration is the possibility of finding life on other worlds. The possibility of finding a second genesis of life (i.e., life not on the tree of life of Earth) would be particularly significant, because it would suggest that at least primitive life is common in the universe. The astrobiology drivers for planetary exploration are also relevant to understanding the early planetary environment and the origin of life on Earth. Finding a second genesis of life in our solar system may require looking at potentially habitable worlds such as Europa and Enceladus that are distant from the Earth to avoid the likelihood of random panspermia between Earth and Mars.

There is evidence that Europa and also probably Enceladus have regions of liquid water, and in some cases, oceans, beneath the ice. Given liquid water on Europa and Enceledus, is there a plausible origin of life and a plausible ecology? Theories for the origin of life indicate that life could have developed on Europa and Enceladus from an extraterrestrial source, that is, by random panspermia. In addition, there could be a terrestrial genesis based on either heterotrophic or chemosynthetic organisms. There are examples of ecologically isolated microbial ecosystems (no oxygen, light, or organic input) on Earth. If Europa's ocean contains life, then the prominent red features on the surface may contain biogenic organic material.

An Ares V enables sample return from Europa, because it has the payload capacity to provide shielding from the harsh radiation environment and mass for Delta-V that is needed either for landing or sample capture. At Enceladus, it could enable sampling from either a natural plume or an artificial plume created by an impact from a projectile. One could envision, for example, an Europa sample return mission based on a Stardust-like spacecraft (e.g., the proposed Europa Ice Clipper) flying through an impact cloud produced by a copper impactor.

IV.3 A Multi-Spacecraft Mission to Saturn Enabled by Ares V: Atmospheric Probes, Ring Observer, and "Beyond Cassini" Orbiters

This paper was presented by Tom Spilker and was co-authored by S. K. Atreya, L. J. Spilker., T. Balint, E. Venkatapathy, and J. O. Arnold (refs. 5-7). The high-level science goals of the mission are to determine the composition of Saturn's atmosphere, particularly heavy element and water abundances, the atmosphere's dynamics and metrology, and Saturn's ring dynamics. The mission scenario consists of two high-speed direct entry probes, microwave radiometry for deep atmosphere sounding, aerocapture of the Saturn Ring Observer (SRO) to study the ring dynamics, and a "Beyond Cassini" orbiter. The shallow probes penetrate to ~10 bars, the deep probes to ~100 bars, and the microwave radiometry down to 100 bars as well. The deep probes, which are dropped from the slower descending shallow probes, provide "ground truth" validation of the microwave radiometry. Multiple probes help ensure a representative sampling of the atmosphere. Total flight system mass is estimated to be 15,000 kg.

The SRO, which is aerocaptured to within a few kilometer of the Saturn ring plane and then co-orbits with the ring particles, will observe the A and B rings for complex ring dynamics such as waves and time varying "clumping" of matter. The multi-spacecraft mission to Saturn should provide a huge advancement in our understanding of outer planet formation and discrimination among giant planet accretion models.

There are a number of technology challenges that need to be addressed in the performance of this mission. These include thermal protection materials for probes and aerocapture, communication from the deep probes, payload performance at high temperatures and pressures, power, and pressure vessels that can operate at 100 bars.

IV.4 Science with Large Planetary Probes Enabled by Ares V: Exploration of the Kuiper Belt

Dale Cruikshank presented a paper that looked at the science that could be enabled at Kuiper Belt Objects (KBOs) with large planetary probes launched on an Ares V. The largest known trans-Neptunian objects are shown in figure 8 compared to the Earth. He began by discussing the science objectives of the New Horizons mission to Pluto and Charon. Missions to large AU require radioisotopes for power. The radioisotope thermal generator on New Horizons provides about 220 W at Pluto. The key science objectives of New Horizons are to characterize the global geology of Pluto and Charon, map their surface composition, and characterize the atmosphere of Pluto. A dedicated mission to explore other objects in the Kuiper belt would have similar objectives and instrument requirements. The origin, composition, and geological processes on the surface and interior of KBOs, as well as their relationship to comets and to the volatile and organic inventory on terrestrial planets are key scientific questions. Specific goals include measuring the surface composition of KBOs with high spatial resolution, determining the isotopic composition of C, H, O, and N using mass spectroscopy, and characterizing their magnetic fields and any satellite objects. To do this properly requires substantial power and payload for scientific instruments.

The Ares V allows a larger capacity for much larger instruments, for example, larger apertures and more capable detectors with larger wavelength range and sensitivity, and more robust mass spec-

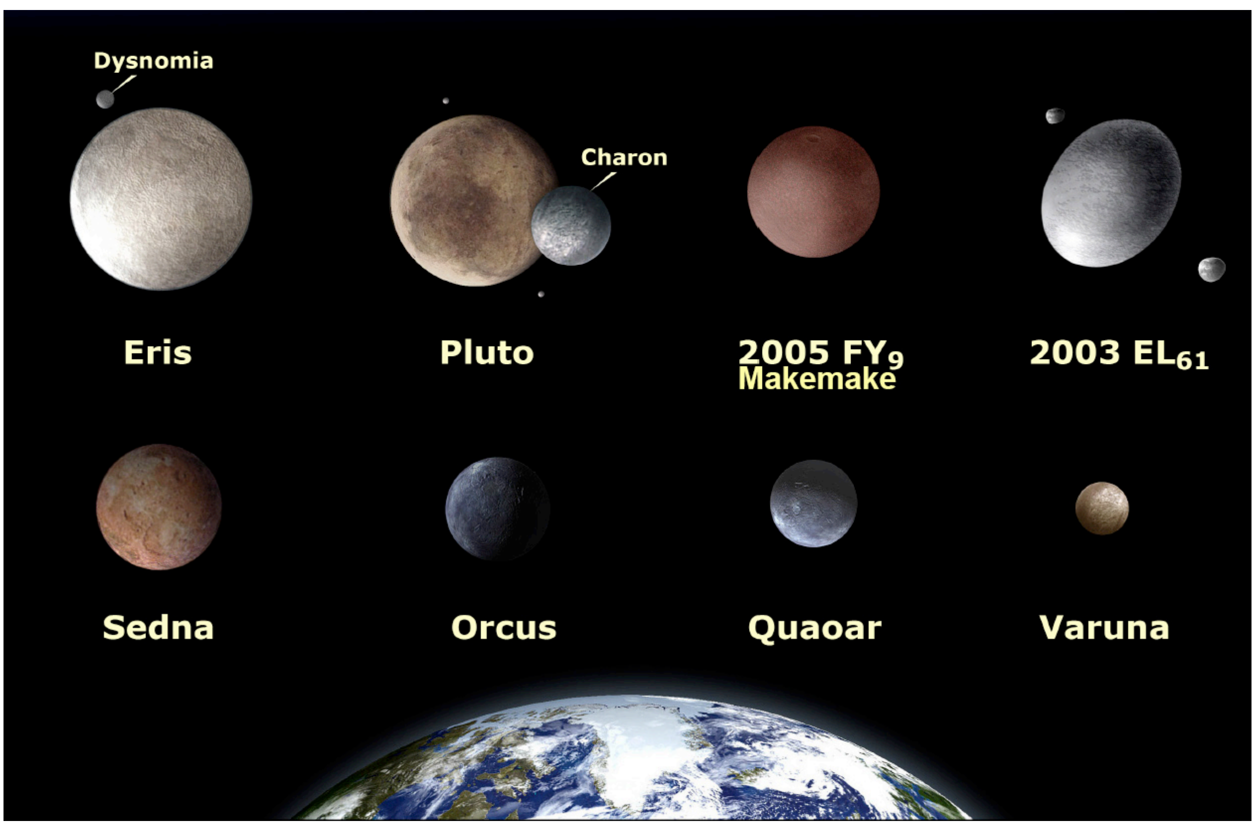

Figure 8. Largest known trans-Neptunian objects (TNOs).

trometers. Furthermore, it enables greater power (>few kW), higher data volume and rate, mass for surface probes, and autonomy for other operational innovations such as laser communications. The Ares V would enable larger science payloads to Pluto and other KBOs.

IV.5 Constellation-Enabled Mars Mission Exhibiting New Technology (CEMMENT) Mars Sample Return Mission

Richard Mattingly presented an overview of the CEMMENT study (ref. 8). The CEMMENT study objectives included looking at what Mars sample return missions can be done, as well as other human-precursor demonstrations, using the Constellation flight elements including the Ares V. Both the sample return and precursor objectives used were those defined by Mars Exploration Program Analysis Group (MEPAG) as Goal-IV: Preparation for Humans to Mars. The study's driving requirements included orbital-aerocapturing and landing large masses with vehicle parameters and trajectories similar to those needed by human missions. Aerocapture of 40 metric tons (mT) and landing of 8 mT were achieved, both roughly half of that anticipated for human missions. The design included a dual-use large ellipse-sled aeroshell and an inflatable hypercone, both requiring substantial technology maturation. All the elements of the mission were launched in the ellipse-sled, which fit comfortably on the Ares V. A schematic of the mission architecture is shown in figure 9.

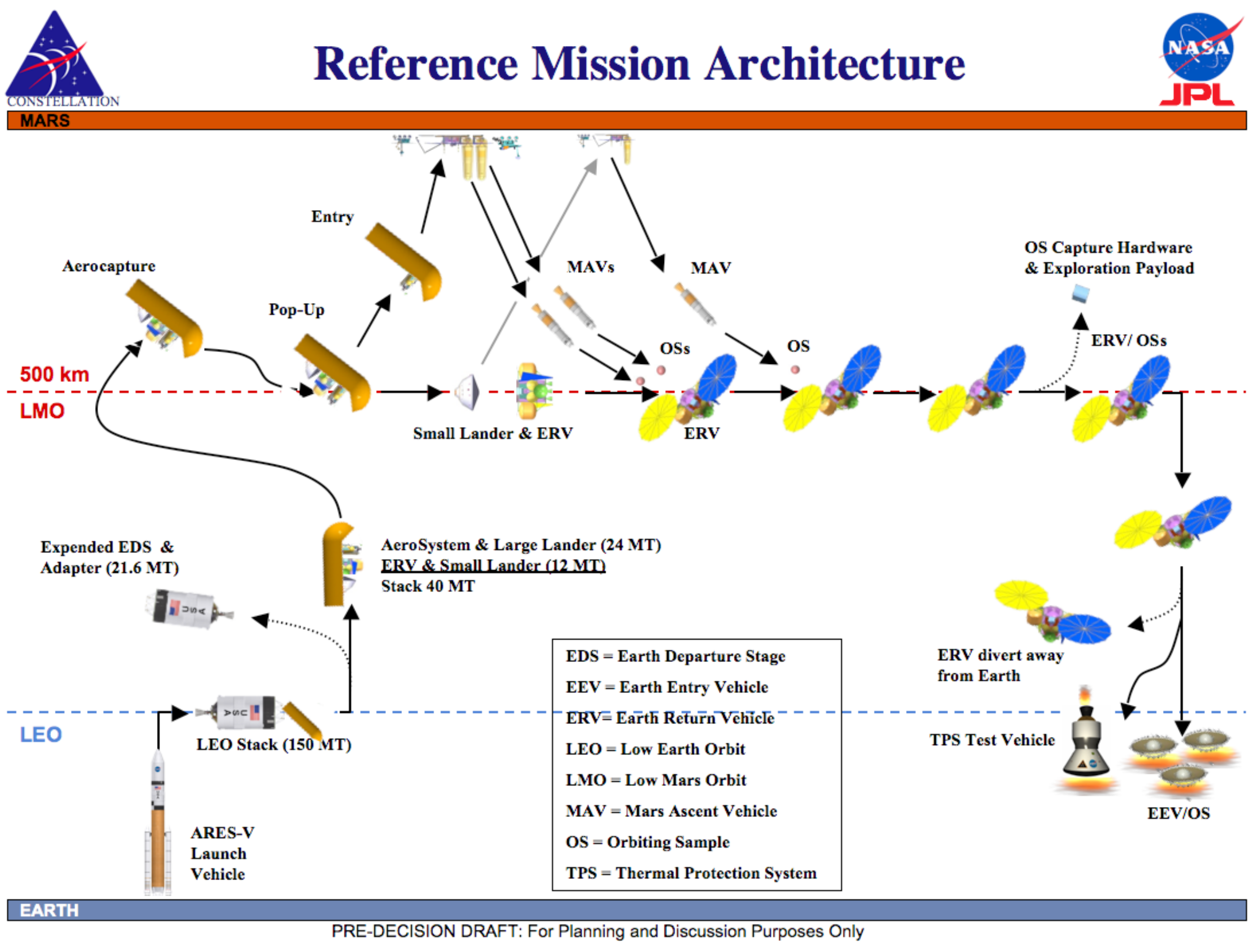

Figure 9.

Three 500 gm separate samples were returned, from two separate Martian locations with an excursion mobility of >1 km, and at one location adding subsurface sampling to a 10-m depth. One sample is taken from a Mars Science Laboratory (MSL) heritage lander, while the other two from a large custom lander equipped with additional investigations. These include extensive in situ sampling and analysis to support science and establish safety of Mars for human missions. Aside from the orbital capture and landing, other human-mission features were demonstrated. These included pinpoint landing, three ascents from the surface, three automated rendezvouses in orbit, three reentries at Earth, a powered reentry demonstration of a thermal protection system (TPS) at fast-return velocity (13 km/sec), robust Earth-Mars communications, and round-trip autonomous navigation.

IV.6 Alternative Approaches to Outer Solar System Exploration

Amy Barr presented a paper that discussed some mission approaches to outer planet exploration. The icy satellites, such as Europa and Enceladus, are scientifically important because the oceans that may lie beneath the ice are potentially habitable, and considering their remoteness from Earth, life in the oceans likely would represent a "second genesis" of life. Studying the interior structures of the geologically inactive and unprocessed regular satellites of Jupiter and Saturn, can shed light on the timing and duration of satellite formation, and by extension, gas giant planet formation. Callisto is an interesting target in this regard, since it is thought to be undifferentiated. She suggested the possibility of putting a small spacecraft like the Gravity Recovery and Interior Laboratory (GRAIL) (ref. 9) on a Jupiter or Europa flagship mission to perform gravity science at Callisto. In the far reaches of the solar system, science questions center around the composition of KBOs, and what this tells us about the solar nebulae from which the planets arose.

Europa is a challenging object for exploration. Although the depth of the ice is still controversial, it is likely that to reach the ocean would require drilling through more than 10 km of ice. The Jovian magnetosphere produces a severe radiation environment that chemically processes the surface, making it necessary to penetrate more than a meter to get a pristine ice sample. The challenges of reaching and surviving on the surface make concepts like the proposed Discovery mission "Europa Ice Clipper" attractive. In this mission scenario, a copper impactor creates an artificial plume, and the Europa Ice Clipper intercepts the ejecta at 50 km altitude using an aerogel collector. With an Ares V, there may be sufficient payload to permit a companion orbiter that would be able to analyze the plume in situ using spectrometers and gas chromatography-mass spectrometers. The Ares V could also enable radiation-hardened electronics or shielding for a long duration orbiter. A similar mission could be attempted for Enceladus, a small active moon of Saturn, where there are natural plumes originating from the moon's south polar region.

Another mission that was discussed was an ice giant orbiter to study the Neptune-Triton system. Since Triton is potentially a captured tidally heated KBO, this could enable comparative planetology for the outer solar system and KBOs. The mission would also have the primary objectives of studying the composition and weather of Neptune, as well as trying to determine whether Neptune has a rocky core with an overlying mantle of ice. The increased performance of the Ares V opens up new mission scenarios using propulsive capture, significantly diminished mission times, and greater scientific payloads.

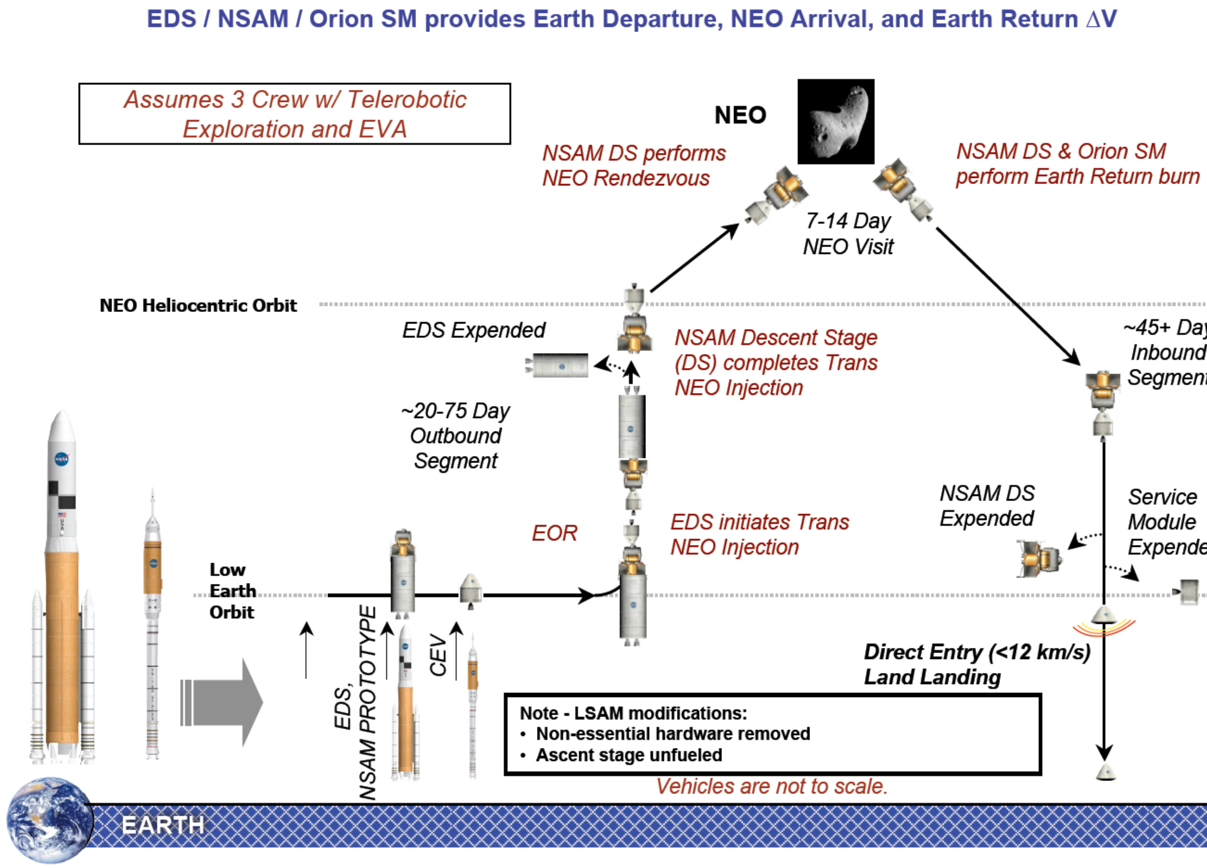

Figure 10. "Upper Bookend" Near-Earth Object (NEO) crewed mission.

IV.7 Constellation Enabled Missions to NEOs

Paul Abell presented a phase one technical feasibility study to determine how Constellation elements might enable a human mission to study a Near-Earth Object (NEO). They considered a number of mission concepts, but this discussion will focus on the more robust mission concept of a dual launch that uses Ares I to loft Orion and the Ares V to loft the Earth Departure Stage (EDS) and the NEO Surface Access Module. The mission scenario is shown in figure 10. Depending on the target, the outbound segment is ~20-75 days, with a 7-14 day visit at the NEO, and a ~45+ day return trip to Earth. The best targets for the mission are NEOs that have Earth-like orbits with low eccentricity and inclination that will have close approaches to Earth during the time frame of 2020-2035. In the current database of existing NEOs, there are nine potential targets that exist within the available Delta-V and mission length capabilities of the proposed Constellation systems. Other targets are expected to be identified in on-going NEO surveys.

There is considerable value in the human exploration of NEOs, for example, to expand human capability to operate beyond Earth orbit, to assess the resource potential of NEOs for exploration and commercial use, to gain operational experience beyond low-Earth orbit, to assess crew psychology for long duration missions, and to help identify more efficient/cost-effective deep space exploration architectures. The science drivers are also strong. Sample return from NEOs will provide ground truth data for terrestrial meteorites, provide insight into solar system formation and evolution, and help us understand the internal structure of NEOs to refine impact physics models that might be useful for mitigating a possible impact threat in the future. This mission would also be a good stepping stone to a human Mars mission and would likely engage the interest of the public. More and better NEO targets of opportunity are needed, as is a more in-depth mission analysis, including human factors issues such as radiation shielding and countermeasures for long duration spaceflight. However, initial studies indicate that the Constellation architecture could enable a human mission to an NEO in the near future.

IV.8 The Human Exploration of Venus

Mark Bullock presented a mission concept where humans would explore the surface of Venus through telepresence robots while in orbit around the planet. This would enable real-time field geology on Venus. The human aspect of the mission is designed to last two years, while the surface robotic mission would last 17 years. Exploration of Venus will help us understand its climate, which is the result of interconnected atmospheric and geological cycles. It will help us understand how terrestrial planets evolve, and help us to interpret spectra from exosolar planets.

Robotic field geologists are needed at multiple locations on Venus to understand its varied geologic history. To survive on the surface, the vehicles must incorporate some combination of high-temperature electronic and mechanical systems, and Stirling-cycle power and cooling. The Ares V will be needed to emplace these large and heavy rovers on the surface. A second Ares V could place humans in orbit around Venus, to enable real-time field geologic exploration that billions of people on Earth could participate in remotely.

What it would be like to be on Venus is depicted in figure 11. The very high surface temperatures and pressures require a concerted effort to keep key electronic components below 50° C. The

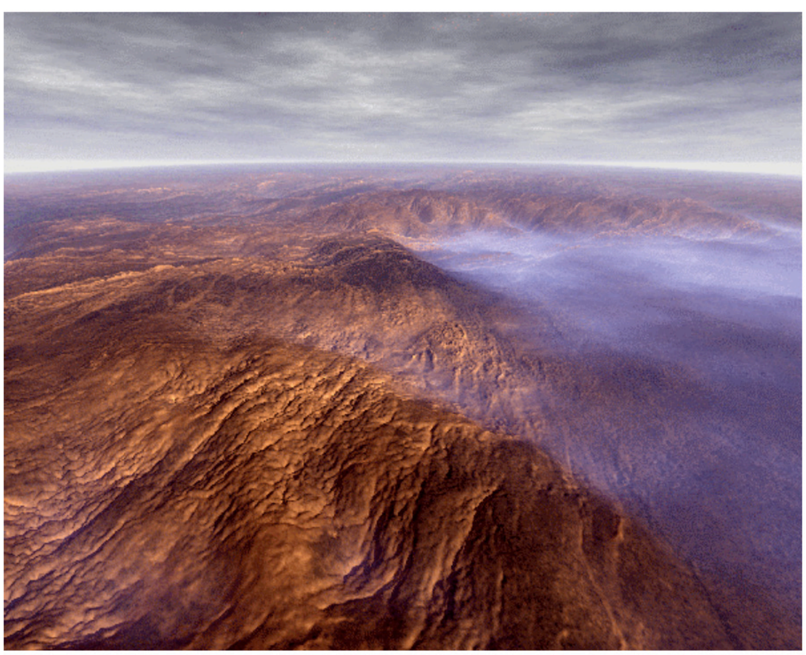

Figure 11. Being on Venus.

Even at night, it is not dark. The plains and foot of the mountains glow dull red.

During the day, the diffuse lighting is modulated by cloud variations overhead. Nearby rocks shimmer in the hot, dense atmosphere, almost as if the observer is at the bottom of an impossibly hot ocean.

preferred approach uses Stirling cycle power generation and two stages of Stirling cycle coolers. Heat is converted to power with approximately 7.6% efficiency. The mission requires twenty 250 W general-purpose heat source modules to provide 80 W of power and 300 W of cooling capacity. Some of the enabling technologies for this mission include high-temperature power electronics, sensors, digital processing, motors, etc. The technology either exists or can be developed to keep the rovers alive on the surface for an extended period of time. The Ares V provides the needed payload capacity (approximately 40 mT to Venus) to enable the mission. The Constellation assets and a second Ares V launch permit a human mission to Venus to carry out real-time field geology on the surface.

V. Earth Science and Heliophysics

V.1 Earth Observation Targets: 2020 and Beyond

Although the Earth Science community has not given a lot of thought to the mission opportunities that an Ares V might enable, we wanted to at least begin this discussion at the workshop. Stewart Moses presented a paper for Ron Birk looking at how the Earth Science community might benefit from an Ares V. To put the Earth Science enterprise in perspective, it should be noted that an armada of current and planned missions exist that will unfold according to recently developed decadal plan recommendations. The Earth Science mission has received impetus from the growing concern over human-induced climate change, which has a potentially large impact on the environment, economy, and national security. A global change monitoring system is needed to provide data to inform decision makers of adaptation and mitigation at local through global levels. Earth is a complex system requiring a full complement of observations of key climate, weather, and solid Earth hazards parameters.

Looking toward the future, the scientific community requires global change information from integrated and layered platforms that can address real-time weather, forecasts of climate change, ocean monitoring, etc. These would consist of surface, airborne (100 km), low-Earth orbiting (850 km), and geostationary (35,800 km) platforms. An Ares V could potentially enable new capability in large GEO platforms. For example, large apertures (>10 m) microwave sounders can provide useful spatial resolutions (<4 km) measurements of temperature and moisture soundings, rain measurements, and severe weather monitoring and prediction. Another possibility is synthetic aperture radars for surface wind measurements. An Ares V could also enable large aperture telescopes at the Sun-Earth Lagrange points (L1 and L2). These vantage points provide a synoptic view, high time resolution, sunrise to sunset coverage, and long integration times (to extract small changes over years). One example of a distant-vantage-point Earth science mission is the L2 Earth Atmosphere Solar-occulation Imager (EASI) (ref. 10) designed to measure greenhouse gases using a 10-m infrared telescope.

V.2 Interstellar Probe Mission

The Ares V performance is also capable of enhancing heliophysics-focused missions. Ralph McNutt presented an Interstellar Probe concept (ref. 11) that is designed to study the nature of the nearby interstellar medium, the structure of the heliosphere, and how the Sun and galaxy affects the heliosphere's dynamics. To reach the heliopause in a reasonable length of time requires the large C_3 capability of the Ares V and its ability to launch an upper stage. Even so, the payload mass is very constrained. The goal is to constrain payload to ~45 kg mass and 40 W power, including ~30% margin for 10 instruments. The low-mass payloads will focus on measuring fields and particles.

All approaches to the Interstellar Probe mission need propulsion development. Under consideration are ballistic, nuclear electric, and solar sail propulsion approaches. The highest flyout speed possible is obtained with a synergistic combination of high launch energy (C_3), gravity assist at Jupiter, and ion engines powered by a high-specific-energy radioisotope power source. This assumes improvements can be achieved in the specific power of current radioisotope sources. The best-case scenario has the Interstellar Probe reaching 200 AU in a little over 20 years with a final velocity in excess of 10 AU/yr. Thus, the probe would reach 1000 AU within 100 years with sufficient power to still operate the spacecraft. It is estimated that an Ares V would speed up arrival to 1000 AU by about 31 years over existing launch vehicles.

VI. Technology Focused Talks on Industry Capabilities

VI.1 Lockheed Martin Sensing and Exploration Systems Planetary Capabilities

Beau Bierhaus presented a paper describing Lockheed Martin's (LM) sensing and exploration systems planetary capabilities. This includes a heritage in meteorology and Earth science, astronomy and physics, and solar system exploration. LM flight experience spans flagship, Mars, and PI-led missions, and it includes expertise in developing spacecraft, major subsystems, and instruments. LM has been an important part of planetary atmospheric entry missions beginning with Viking (1976) and continuing through to the Mars Science Lab (MSL) in 2009. Their core spacecraft capabilities include multiple generations of composite structures, proven flight software, mission operations, and engineering, assembly and testing facilities. Recent missions where they have had a mission operations role include the Spitzer Space Telescope, the Mars Reconnaissance Orbiter, and Phoenix. They have built a wide range of instruments, including visible imagers, multi-spectral infrared imagers, radar, magnetometers, etc. Thus their capability to design, build, test, and operate a wide range of spacecraft architectures and the ability to support multiple spacecraft will have direct relevance to missions involving the Ares V.

Based on their experience, they provided the following considerations for the Ares team. First, provide multiple spacecraft payload capability—both a small number of large vehicles, and a large number of small vehicles. Also the shroud should be able to accommodate different geometric positioning, e.g., vertical stacking versus segmented. There should be access to the payload late in the launch process, for example, the ability to put nuclear components in as late as possible. Finally, there should be thought to providing cleanliness, purges, and thermal accommodation. These points are again emphasized in the breakout session that discussed payload development and accommodation issues (see later discussion).

VI.2 Planetary Exploration Possibilities Enabled by the Ares V Launch Vehicle

Stewart Moses gave a paper describing Northrop Grumman's view of planetary exploration possibilities enabled by the Ares V. They looked both at enhancements of previous missions and new missions that would be enabled by an Ares V. New mission opportunities considered by Northrop Grumman include an Europa lander/penetrator to characterize Europa's ice shell and underlying ocean, a Mercury polar lander/rover to confirm the presence of water ice, a Titan sample return mission, a Triton orbiter/lander to understand Triton's atmosphere, a Neptune orbiter to characterize Neptune's composition, gravity field, and magnetosphere, an Io orbiter to characterize the tidal heating and internal processes of Io, a Pluto/Charon orbiter, and a number of asteroid and comet missions. They proposed an Ares V launch of twin operational atmospheric observing satellites at Venus to achieve both high-resolution radar terrain mapping and sub-surface mapping. Also discussed was the feasibility of a Titan observing system to study the atmosphere and global distribution of organic compounds.

The Mercury polar lander concept was described in some detail. It would involve launch of a Mercury rover on an Ares V, transfer to Mercury via two Venus gravity assists, propulsive capture at Mercury, orbit circularization, lander and rover deployment, and finally surface operations with direct communication back to Earth. The rover would enable the in-situ study of water ice and geological composition. An ambitious Titan sample return mission was also discussed that involved launching both an orbiter and lander on an Ares V. Both the lander and the orbiter would use aerocapture at Titan after a Venus-Venus-Earth-Jupiter-Saturn gravity assist. The lander would parachute to the surface to carry out surface operations and sample collection. The lander would return for rendezvous with the orbiter using a two-stage propulsion system. Finally, the orbiter would return to Earth with the Titan sample. Collecting samples from the surface would be key to understanding the complex chemistry occurring there. This mission would likely confirm the Cassini radar images that suggest the existence of hydrocarbon lakes on the surface.

VI.3 Payload Processing Capabilities in Support of Ares V Planetary Missions

Shelley LeRoy presented a paper describing Boeing's payload processing capabilities that could support Ares V planetary missions. It was stressed that spacecraft processing is fundamentally different from launch vehicle processing, but understanding both ensures optimal interfacing, servicing, and operation. Current experience at the Space Station Processing Facility (SSPF) at Kennedy Space Center (KSC) is for payloads less than 4.5 m in diameter, which is far less than the expected 8.8 m diameter of future Ares V payloads. These larger diameters pose a number of shroud encapsulation issues for the Ares V at the SSPF.

The payload processing capabilities in the vicinity of KSC include spacecraft lifting and handling, assembly and checkout, and engineering support. A strong argument was made for including launch processing features early in the design cycle of the Ares V to reduce life-cycle cost and schedule risk. Payload processing issues include how to transport 8.8 m payloads to KSC, access to payloads on the pad, umbilicals to "active" payloads, and the acoustical, thermal, and cleanliness environment inside the fairing. Payload processing requirements are large life cycle cost drivers if they are developed too late in the design process. Ares V class payload processing requirements need to be defined soon to support future planning, such as the need for new infrastructure. Boeing is developing the production, flight analysis, and simulation software to enhance understanding of payload processing issues. LeRoy ended his presentation with a demonstration of a simulation of flight operations called ICON (Interactive Concept of Operations). One of the impressive aspects of the simulation is that it is interactive, which gives the user an opportunity to explore various off-nominal scenarios.

VII. Breakout Sessions

In the afternoon, the workshop participants broke into two groups to discuss specific questions in more detail. The first group chaired by Chris McKay looked at sample return missions that could be enabled by an Ares V. The second group chaired by Gary Martin addressed both technological and environmental payload development issues that need to be addressed for launching planetary payloads in the Ares V shroud. The key results of these two breakout groups are discussed in this section.

VII.1 Sample Return Using an Ares V

The first breakout group chaired by Chris McKay considered how an Ares V could either enhance or enable sample return. The group considered sample return missions to have high science value, but to be somewhat beyond the capability of current launch systems. However, that is fundamentally changed by the much higher payload mass capability that Ares V can deliver throughout the solar system. The extra mass provides flexibility to solve mission problems, such as the need for simultaneous orbiters and landers, and shielding against radiation, micrometeorites, or other environmental hazards. It can enable multiple site selection, help deal with planetary protection issues on both the outgoing and return flights, and provide for shorter flight times and longer data acquisition times. It results in a mission with lower risk and greater science return per dollar.

Mars sample return

As discussed previously in the CEMMENT presentation (see section IV.5), the Ares V enables landing at multiple sites that are widely separated geographically. This allows geological questions related to regional transport, relative age dating, and global features (hemispheric dichotomy) to be addressed. Multiple sites also improve the chance of finding life, considering the obvious planetary diversity of Mars. As stated previously, the Ares V has the extra mass needed to address planetary protection issues that are particularly acute for return from Mars. It also has the mass to carry better sample acquisition tools, such as deep drills, and sample analysis tools like X-ray fluorescence.

Europa/Enceladus sample return

The Ares V enables putting a lander on the surface that has the mass and shielding (at Europa) necessary to remain on the surface to carry out subsurface sampling. Ideally the lander would have the mobility to search for a young or active site. Also, to return the sample to Earth would argue for simultaneous orbiter and lander missions. Since it would be necessary to keep the sample cold, mass for refrigeration would be needed for the return flight. Another mission scenario is to perform impact sampling using just an orbiter by firing a copper projectile at the surface. Again the capabilities of the Ares V would be needed to slow the vehicle for sample collection, and then again for reacceleration out of Jupiter's gravity well. This second scenario would be particularly appropriate for Enceladus due to the natural plumes emanating from the south polar region. Sampling of Saturn's diffuse E ring would also be useful to determine its association with Enceladus.

Venus sample return

A vehicle of Ares V capability is probably necessary to enable sample return from Venus for a variety of reasons. Most importantly the high surface temperature, acidity, and pressures impose complex sample acquisition problems that need robust landers and ascent vehicles. Multiple rovers are also warranted due to the geological diversity of Venus. As discussed previously in section IV.8, a robust cooling system is required for survival on the surface. Finally, a large Delta-V capability is needed to get out of the gravitational well of Venus. This all translates to large payload mass requirements.

Titan sample return

Due to the surface processing that occurs on the surface of Titan, sample return should include both atmospheric and surface samples. The extremely cold surface temperatures (~-180° C) may complicate sample acquisition. The geological diversity also warrants sample collection at multiple sites, for example, from surface liquid and a possible cryovolcanism site. Preservation of samples requires a refrigeration system under O_2 free conditions. One scenario for a Titan mission was described earlier (see section VI.2). Clearly, the complexity of a Titan sample mission would greatly benefit from the large payload mass that an Ares V could deliver.

Sample missions to asteroids and comets

The Ares V would allow access to more Near-Earth Objects (NEOs), because of its larger Delta-V capabilities. It could enable visiting several asteroids on the same mission. As discussed previously, it could enable human exploration of a NEO by using other Constellation assets (see section IV.7). Comets also require a large Delta-V for rendezvous as well as propulsion to remain near the comet for extended sampling. Preservation of the sample requires refrigeration under O_2 free conditions similar to that for Titan.

Implications for sample return missions

The fact that an Ares V can enable sample return suggests that the science community should start thinking of the infrastructure to prepare for sample return, for example, flight development, containment, and curation facilities. Other technologies need to be matured as well, such as aerocapture and thermal protection systems.

VII.2 Payload Development and Accommodation Issues

The second breakout session considered payload development and accommodation issues for planetary missions. Since current and next generation radioactive power sources are important for planetary missions, especially to the outer solar system, the design of the Ares V should not prevent their use. In addition, there should be late access on the pad to the shroud for installing nuclear powered payloads, for fueling an upper stage vehicle (e.g., a Centaur), and for late integration and maintenance. There should be provision for multi-spacecraft payload capability. The group suggested considering a standard Altair adapter, a generic interface definition, an Evolved Secondary Payload Adapter (ESPA) (ref.12), and shroud load-sharing capability.

Accommodation issues included dealing with planetary protection issues by maintaining a high degree of cleanliness. In addition, a provision is needed for handling hazardous propellants and oxidizers, such as nitrogen tetraoxide (NTO) and hydrazine, for long duration missions. Consideration should be given to hazardous material monitoring, handling, and venting. On the pad, the group recommended a continuous N_2 purge, umbilicals for active payloads, and adequate data and power accommodation.

The group recommended that acoustical, vibrational, and thermal loads not exceed those on current heavy-lift vehicles such as Delta IV Heavy. There was concern as to whether the current Ares design that puts a 500-second limit on engine burns would negatively impact planetary missions requiring a high C_3. This remains an open question, but was not thought to be a serious limitation.

With the lengthening of the SRBs to 5.5 segments, the issue of volume constraints on the payload was raised when a Centaur upper stage was employed. The length of the shroud is currently limited by the height of the VAB at KSC. However, most planetary missions achieve sufficient C_3 without an upper stage; notable exceptions are direct-transfer missions to the outer solar system. Furthermore, missions like the Interstellar Probe mission (section V.2), which would definitely employ an upper stage, would still have room to accommodate the payload on top of the Centaur. Replacing the current baseline biconic shape with the alternative ogive-shaped shroud would also provide additional shroud volume, and thus would be more favorable for planetary missions. Finally, by the early 2020's when the Ares V will be available for planetary missions, these height constraints may no longer be an issue.

VIII. Future Directions—How to Get the Message Out?

The general consensus at the workshop was that the Ares V, and other Constellation assets, have the potential to significantly impact planetary science. In the final session, the workshop participants primarily discussed how to deliver this message to the rest of the planetary science community. Preparations have already begun for the next planetary decadal survey, which is expected to start sometime in the first half of 2009. If the potential of Ares V is to be considered by future decadal panels, its capabilities must be presented to planetary science communities. The first attempt to do so was at the International Astronautical Congress (IAC) meeting in Scotland in October 2008. The opportunity to present the potential of this vehicle for solar system science was especially important, because of the participation and attendance of the international community. International partnerships will be particularly important for future flagship missions that Ares V will enable in the not-to-distant future.

The previous workshop on astronomy and this one on solar system science are a first step. The results of both workshops are published as NASA Conference Proceedings (this report and ref. 3). Further impetus for bringing the message to the science community should come from the National Research Council (NRC) report that came out in November of 2008. Hopefully these reports will help catalyze the astronomy and planetary science communities to consider the new missions that will be enabled by the Constellation architecture.

IX. Concluding Thoughts

This workshop and the previous one, which examined future astronomy missions (ref. 3), has shown that the Ares V vehicle changes the paradigm of what science payloads can be launched, because the vehicle's launch performance (C_3 versus payload) and larger fairing diameter represent a dramatic improvement over existing vehicle capabilities. It is particularly enabling for sample return, which takes advantage of all of the Ares V capabilities.

One concept that arose from both workshops is whether the large mass and volume capabilities of the Ares V can be used to trade off complexity and thereby reduce technology development and integration costs. For example, there are many ways to use "cheap" mass to augment mission capability, such as inert mass (e.g., combinations of tungsten, copper, and hydrocarbons) for shielding, fuel for propulsive maneuvers, and redundancy. The large fairing makes feasible launching large monolithic mirrors that may be less costly to build and less risky to deploy. The Ares V vehicle not only changes what missions are possible, but also has the potential to alter the way the scientific community historically manages and designs spacecraft and missions. These ideas deserve further study and possibly the investment of funds to perform trade studies that would take this analysis to a higher level of fidelity.

References

1. Aldridge, Jr., E. et. al. Report of the President's Commission on Implementation of United States Space Exploration Policy. June 2004. The Aldridge report is available on the internet at http://www.nasa.gov/pdf/60736main_M2M_report_small.pdf). Accessed December 8, 2008.

2. Details of the Constellation program are available on the web at http://www.nasa.gov/mission_pages/constellation/ares/aresV.html. Accessed December 8, 2008.

3. Langhoff, S.; Lester, D.; Thronson, H.; and Correll, R.: Workshop Report on Astronomy Enabled by Ares V. NASA/CP-2008-214588, 2008.

4. Reh, K. et al.: Ares V: Application to Solar System Scientific Exploration. JPL D-41883, 2007.

5. Atreya, S. K. et al.: Formation of Giant Planets and Their Atmospheres: Entry Probes for Saturn and Beyond. 5th International Planetary Probe Workshop, Bordeaux, France, June 2007.

6. Spilker, T. R.: Saturn Ring Observer. IAA-L-00604, 2000.

7. Venkatapathy, E. et. al.: Thermal Protection System Development, Testing, and Qualification for Atmospheric Probes and Sample Return Missions. COSPAR Symposium, Montreal, Canada, June 2008.

8. Mattingly, R.: Constellation-Enabled Mars Mission Exhibiting New Technology (CEMMENT) Study. The study can be downloaded from http://event.arc.nasa.gov/aresv-sss/home/ppt/AresV-sss/SAT/pm/11Mattingly/CEMMENTAMESARES-VWS.pdf. Accessed December 8 2008.

9. The GRAIL mission is described at-http://www.lockheedmartin.com/news/press_releases/2007/1219-grail.html. Accessed December 8, 2008.

10. Herman, J. et. al.: Earth Atmosphere Solar Occultation Imager. Presentation available on line at http://esto.nasa.gov/files/2000/Atm%20Chem%20from%20L1/Herman_Final%20Report.pdf. Accessed December 8, 2008.

11. Mewaldt, R. A. and Liewer, P. C.: An Interstellar Probe Mission to the Boundaries of the Heliosphere and Nearby Interstellar Space. The paper is available on the internet at http://interstellar.jpl.nasa.gov/interstellar/ISP_Space2K_v4.pdf. Accessed December 8, 2008.

12. See for example, Minelli, B. et al., for an excellent discussion of secondary payload adapters for evolved expendable launch vehicles, available on the internet at http://www.aeroastro.com/publications/SSC03-II-7.pdf. Accessed December 8, 2008.

Ares V Solar System Science Agenda

		DAY ONE Sat, August 16th	
Time	min	Description	Speakers & Discussion leaders
8:00	30	Breakfast	
8:30	5	Logistics	Stephanie Langhoff
8:35	10	Welcome/objectives	Pete Worden
8:45	15	Introduction of participants	Stephanie Langhoff
9:00	20	Overview of Planetary Division Objectives	James Green
9:20	20	Discussion	
Ares-V Capability			Greg Sullivan
9:40	30	FOUNDATIONAL TALK: Constellation Overview	John Horack
10:10	20	Discussion	
10:30	15	Break	
10:45	40	Ares V Overview and Performance w/wo Centaur Upper Stage	Phil Sumrall
11:25	30	Discussion	
11:55	20	Science operational capabilities enabled by Ares-V performance	Tom Spilker
12:15	20	Discussion	
12:35	60	Lunch	
Solar System Concepts- Planetary			Jennifer Heldmann
13:35	15	A Brief Overview of Potential Planetary Exploration enabled by Ares V"	Gordon Chin
13:50	15	Discussion	
14:05	15	Interstellar Precursor Probe	Ralph McNutt
14:20	15	Discussion	
14:35	15	Sample return from Icy Outer Solar System Moons with Ares V	Chris McKay
14:50	15	Discussion	
15:05	15	Break	
15:20	15	Saturn multi-probes and ring observer Aerocpature Mission	T. Spilker, S. Atreya, L. Spilker, T. Balint, E. Venkatapathy and J. Arnold
15:35	15	Discussion	
15:50	15	Missions to the Kuiper belt	Dale Cruikshank
16:05	15	Discussion	
16:20	15	Mars Sample Return using an Ares V	Richard Mattingly
16:35	15	Discussion	
16:50	15	Alternate Strategies for Exploration of Europa, Enceladus, & Triton	Amy Barr
17:05	15	Discussion	
17:20	40	Wine and cheese social	
18:00		Adjorn	
19:00		DINNER: Chef Chu's, 1067 N San Antonio Rd, Los Altos	

Ares V Solar System Science Agenda

		DAY TWO Sun., August 17th	
Time	**Dur. min**	**Description**	**Speakers & Discussion leaders**
8:00	30	Breakfast	
Solar System Concepts- Planetary- con't			**Stephanie Langhoff**
8:30	15	Constellation Enabled Missions to NEOs	Paul Abell/Rob Landis
8:45	15	Discussion	
9:00	15	Science at Venus with an Ares V	Mark Bullock
9:15	15	Discussion	
Solar System Concepts- Earth Science and Heliophysics			**Stephanie Langhoff**
9:30	15	Earth Observation Targets: 2020 and Beyond	Stewart Moses
9:45	15	Discussion	
Technology challenges			**Richard Tyson**
10:00	15	Lockheed Martin capabilities to support planetary missions enabled by ARES	Beau Bierhaus
10:15	15	Discussion	
10:30	15	Planetary Exploration Possibilities Enabled by the Ares-V Launch Vehicle	Stewart Moses
10:45	15	Discussion	
11:00	15	Boeing capabilities to support planetary missions enabled by ARES	Shelly LeRoy
11:15	15	Discussion	
11:30	10	Ares-V Interactive Concept of Operations (ICON)	Shelly LeRoy
11:40	10	Discussion	
11:45	60	Lunch	
Breakout Sessions			
12:45	90	(1) Sample return with an Ares V (2) Payload development and accommodation: Technological and environmental issues	Chairs: 1-Chris McKay, 2-Gary Martin
14:15	15	Break	
14:30	30	Reporting of breakout groups	Session Chairs
15:00	45	DISCUSSION: Research priorities- where do we go from here?	Yvonne Pendleton
15:45		Adjourn	

List of Participants

NAME	EMAIL	AFFILIATION
Abell, Paul	paul.a.abell@nasa.gov	NASA JSC
Alexander, Reginald	reginald.alexander@nasa.gov	NASA MSFC
Arnold, James	James.O.Arnold@nasa.gov	NASA ARC
Barr, Amy	amy@boulder.swri.edu.	SWI
Bierhaus, Beau	edward.b.bierhaus@lmco.com	LM Denver
Boyd, Jack	John.W.Boyd@nasa.gov	NASA ARC
Bullock, Mark	bullock@boulder.swri.edu	SWRI
Carroll, Carol	Carol.W.Carroll@nasa.gov	NASA ARC
Chin, Gordon	gordon.chin-1@nasa.gov	NASA GSFC
Chivatero, Craig	craig.chivatero@lmco.com	LMCO
Colaprete, Anthony	anthony.colaprete-1@nasa.gov	NASA ARC
Cruikshank, Dale	dale.p.cruikshank@nasa.gov	NASA ARC
Cuzzi, Jeffrey	Jeffrey.N.Cuzzi@nasa.gov	NASA ARC
Day, Dwayne	Dday@nas.edu	NRC
Frampton, Robert	robert.v.frampton@boeing.com	Boeing
Gonzales, Andy	agonzales@arc.nasa.gov	NASA ARC
Green, James	james.green@nasa.gov	NASA Hdqs
Haberle, Robert	robert.m.haberle@nasa.gov>	NASA ARC
Heldmann, Jennifer	jennifer.heldmann@nasa.gov	NASA ARC
Horack, John	john.m.horack@nasa.gov	NASA MSFC
Irons, John	John.J.Irons@nasa.gov	NASA MSFC
Karcz, John	jkarcz@arc.nasa.gov	NASA ARC
Kuck, Frederick	Frederick.Kuck@pwr.utc.com	Pratt-Whitney
Landis, Rob	rob.r.landis@nasa.gov	NASA JSC
Langhoff, Stephanie	slanghoff@mail.arc.nasa.gov	NASA ARC
Le Roy, Shelly	shelley.j.leroy@boeing.com	Boeing
Lemke, Larry	llemke@mail.arc.nasa.gov	NASA ARC
Levit, Creon	Creon.Levit@nasa.gov	NASA ARC
MacDonald, Alexander	alexander.c.macdonald@nasa.gov	NASA ARC
Martin, Gary	gmartin@nasa.gov	NASA ARC
Mattingly, Richard	Richard.L.Mattingly@jpl.nasa.gov	JPL

List of Participants

NAME	AFFILIATION	
McKay, Christopher	christopher.mckay@nasa.gov	NASA ARC
McNutt, Ralph	ralph.mcnutt@jhuapl.edu	Applied Physics Lab
Morris, Bruce	Bruce.Morris@nasa.gov	NASA MSFC
Moses, Stewart	stewart.moses@ngc.com	NGC
Pendleton, Yvonne	yvonne.pendleton@nasa.gov	NASA ARC
Sandford, Scott	scott.sandford@nasa.gov	NASA ARC
Spilker, Linda	linda.j.spilker@nasa.gov	JPL
Spilker, Thomas	thomas.r.spilker@nasa.gov	JPL
Stahl, Philip	h.philip.stahl@nasa.gov	NASA MSFC
Sullivan, Greg	GPS@AOL.COM	NASA, MSFC
Sumrall, Phil	john.p.sumrall@nasa.gov	NASA, MSFC
Tenerelli, Dom	domenick.tenerelli@lmco.com	LMCO
Thronson, Harley	harley.a.thronson@nasa.gov	NASA GSFC
Tyson, Richard	richard.w.tyson@nasa.gov	NASA MSFC
VanCleve, Jeff	jvanclev@ball.com	Ball Aerospace
Weston, Alan	alan.r.weston@nasa.gov	NASA ARC
Worden, Pete	Simon.P.Worden@nasa.gov	NASA ARC
Zahnle, Kevin	Kevin.J.Zahnle@nasa.gov	NASA ARC