Update on the Ares V to Support Heavy Lift for U.S. Space Exploration Policy

John P. Sumrall, Advanced Planning Manager
Ares Projects Office
Marshall Space Flight Center
Huntsville, AL 35812

Abstract

When NASA's Ares V cargo launch vehicle (Figure 1) begins flying late next decade, its capabilities will significantly exceed the 1960s-era Saturn V. It will send more crew and cargo to more places on the lunar surface than Apollo and will support a permanent lunar outpost. Moreover, it will restore the United States' heavy-lift capability, which can support human and robotic exploration for decades to come.
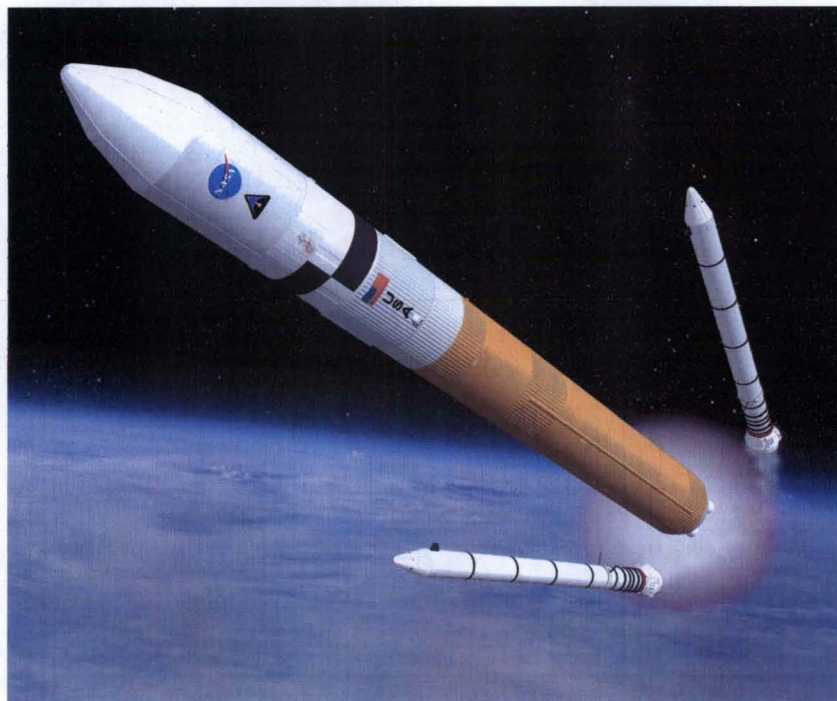
Figure 1. The first stage boosters fall away from the Ares V as it climbs to orbit in this NASA artist's concept.

The Ares V is part of an exploration architecture that includes the Ares I crew launch vehicle, Orion crew exploration vehicle, and Altair lunar lander. The Ares V will loft the Earth departure stage (EDS), carrying the Altair lander, into low Earth orbit (LEO). The Ares I will put Orion into a rendezvous orbit. Once Orion docks with Altair, the EDS will initiate a trans-lunar injection (TLI) burn to head toward the Moon.

According to the latest configuration studies, Ares V will be approximately 361.9 feet tall and will deliver 128.8 metric tons (283,913 pounds) to LEO or 54.2 metric tons (119,521 pounds) to TLI. The Ares V first

stage propulsion system consists of a core stage powered by five commercial liquid hydrogen/liquid oxygen (LH$_2$/LOX) RS-68 engines, flanked by two five-segment solid rocket boosters (SRBs) based on the Ares I first stage. Atop the core stage is the EDS, powered by a single J-2X upper stage engine based on the Ares I upper stage engine.

Ares V remains in a pre-design analysis cycle stage pending a planned late calendar 2010 Authority to Proceed (ATP). However, Ares V benefits from the decision to use heritage hardware as a point of departure for the Ares vehicles and from the goal to seek commonality between the two launch vehicles.

Most Ares V-specific work to date has focused on the core stage's commercial RS-68 engine, currently in use on the Delta IV launch vehicle. Ares V requirements will benefit from a current Air Force effort improve the thrust and efficiency of the engine. NASA is pursuing additional changes to extend exhaust nozzle life, reduce free hydrogen on the launch pad, and reduce helium usage. The Ares Project continues refining the Ares V design through a variety of internal studies. This paper will provide background information on the Ares V architecture and a status report on the latest technical and programmatic progress of the vehicle.

IAC-08-D2.8

UPDATE ON THE ARES V TO SUPPORT HEAVY LIFT
FOR U.S. SPACE EXPLORATION POLICY

John P. Sumrall
NASA Marshall Space Flight Center, USA
John.P.Sumrall@nasa.gov
Steve Creech
NASA Marshall Space Flight Center, USA
Marshall Space Flight Center
Stephen.Cook@nasa.gov

ABSTRACT

When NASA's Ares V cargo launch vehicle (Figure 1) begins flying late next decade, its capabilities will significantly exceed the 1960s-era Saturn V. 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 that will open the Moon to greater exploration, science and adventure than ever before. Moreover, it will restore the United States' heavy-lift capability, which can support human and robotic exploration for decades to come. Ares V remains in a pre-design analysis cycle stage pending a planned Authority to Proceed (ATP) in late 2010. Ares V benefits from the decision to draw from heritage hardware and its commonality with the Ares I crew launch vehicle, which completed its preliminary design review (PDR) in September 2008. Most of the work on Ares V to date has been focused on refining the vehicle design through a variety of internal studies. This paper will provide background information on the Ares V evolution, emphasizing the vehicle configuration as it exists today.

Fig. 1: The Ares V cargo launch vehicle (foreground) and Ares I crew launch vehicle (background) will form the backbone of America's new space fleet. (NASA artist's concept)

I. Introduction

The Ares V is part of a NASA exploration architecture that includes the Ares I crew launch vehicle, Orion crew exploration vehicle, and Altair lunar lander. The Ares V is designed to loft the Earth departure stage (EDS), carrying 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 or a crew of four for rendezvous with the Ares V 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 simpler Ares I, and placing cargo on the larger, more complex Ares V. Both were designed to be safer, more reliable, and more efficient than the Space Shuttle fleet and its associated infrastructure. 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.

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.
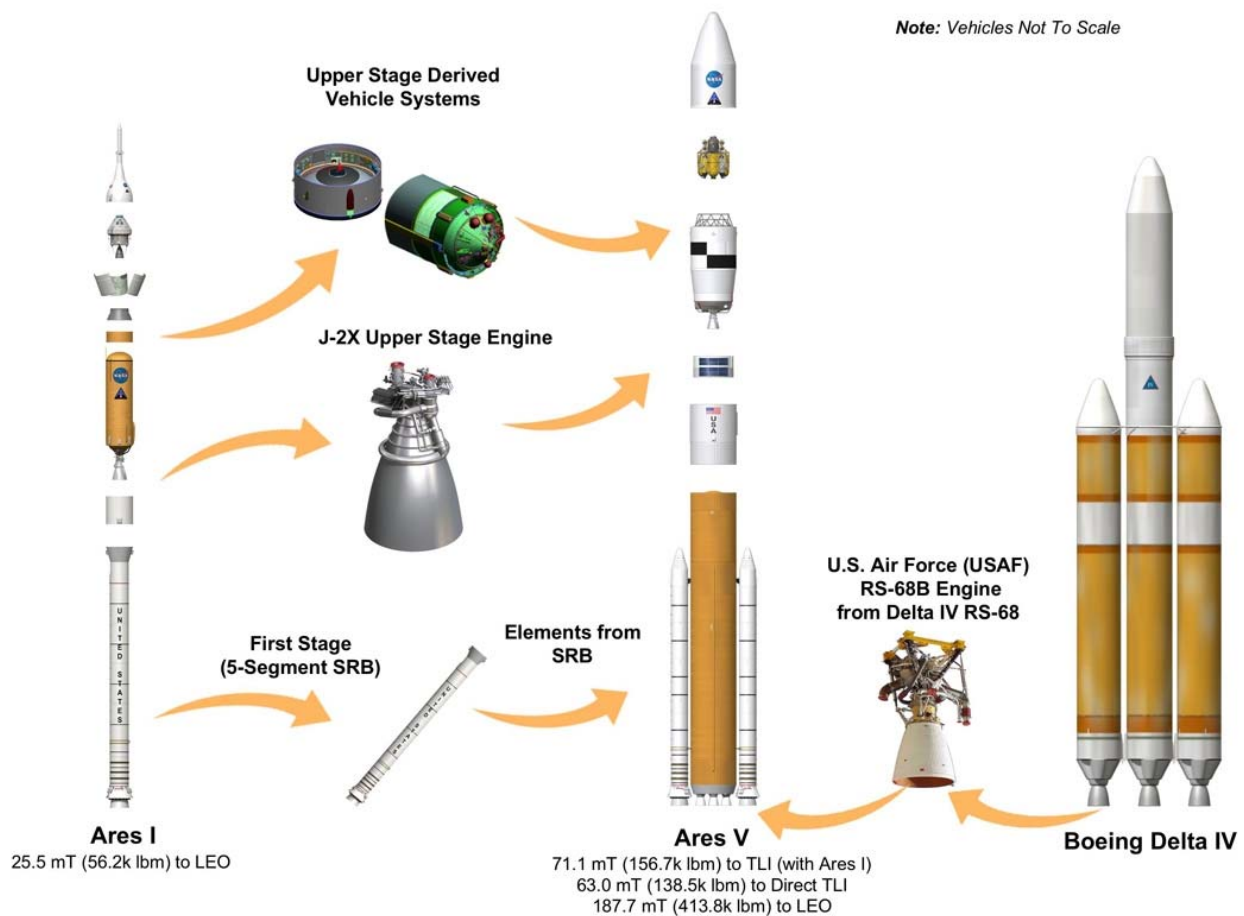

Fig. 2: Heritage hardware and commonality between Ares vehicles remains a key goal.

II. Current 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 most recent point-of-departure (POD) configuration was recommended by the Ares Projects and approved by the Constellation Program during the Lunar Capabilities Concept Review (LCCR) in June 2008. This configuration is the basis for the ongoing Ares V Integration Study which seeks to define and resolve design issues between the Constellation require-ments and interrelationships between major Ares V components.

The latest POD 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 low Earth orbit (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.

By comparison, the Apollo-era Saturn V was 364 feet (111 m) tall, with a gross liftoff mass of 6.5 million pounds (2,948.4 mT), and could carry 99,000 pounds (44.9 mT) to TLI or 262,000 pounds (118.8 mT) to LEO. In conjunction with Ares I, Ares V can launch 58 percent more payload to TLI than the Saturn V.

As shown in the expanded vehicle overview (Figure 3), the Ares V first stage propulsion system consists of a Core Stage powered by six commercial liquid hydrogen/liquid oxygen (LH_2/LOX) RS-68 engines, flanked by two 5.5-segment solid rocket boosters (SRBs) based on the 5-segment Ares I First Stage. The boosters use the same Polybutadiene Acryl-onitrile (PBAN) propellant as the Ares I and Space Shuttle. Atop the Core Stage is the Earth departure stage (EDS), powered by a single J-2X upper stage engine based on the Ares I upper stage engine.

This configuration and its performance is based on a 99,208 pound (45 mT) crew lander and a 44,500-pound (20.2 mT) Orion, plus margin, as stated in the Constellation Architecture Requirements Document (CARD). However, it falls short of an Ares Projects
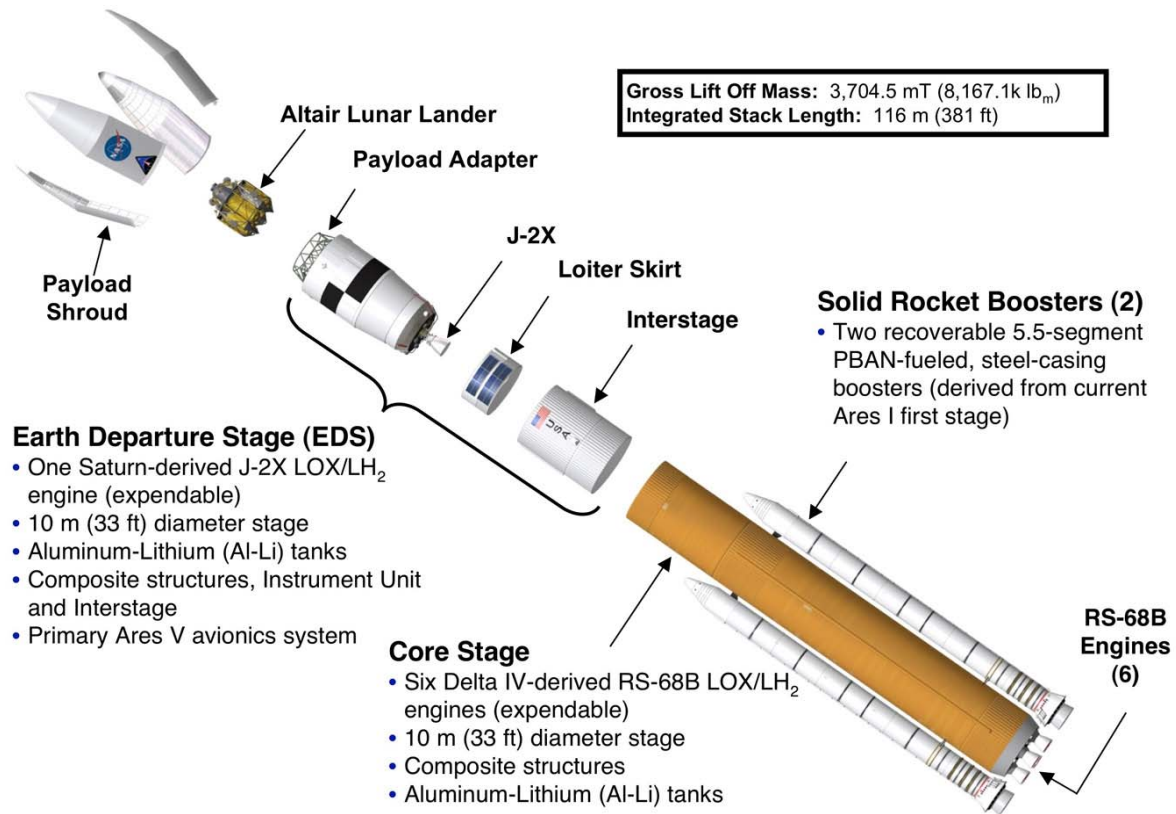

Gross Lift Off Mass: 3,704.5 mT (8,167.1k lb$_m$)
Integrated Stack Length: 116 m (381 ft)

Altair Lunar Lander

Payload Adapter

J-2X

Loiter Skirt

Payload Shroud

Interstage

Solid Rocket Boosters (2)
• Two recoverable 5.5-segment PBAN-fueled, steel-casing boosters (derived from current Ares I first stage)

Earth Departure Stage (EDS)
• One Saturn-derived J-2X LOX/LH_2 engine (expendable)
• 10 m (33 ft) diameter stage
• Aluminum-Lithium (Al-Li) tanks
• Composite structures, Instrument Unit and Interstage
• Primary Ares V avionics system

Core Stage
• Six Delta IV-derived RS-68B LOX/LH_2 engines (expendable)
• 10 m (33 ft) diameter stage
• Composite structures
• Aluminum-Lithium (Al-Li) tanks

RS-68B Engines (6)

Fig. 3: An expanded view of the major Ares V elements (NASA artist's concept).

internal TLI payload goal of 165,567 pounds (75.1 mT) that attempts to accommodate potential growth of Ares and Altair and a corresponding growth in Ares V. The Ares Projects are carrying an option for a new composite case booster with more energetic Hydroxyl-terminated Poly-butadiene (HTPB) propellant which would meet the desired TLI goal.

In the current mission profile (Figure 4), the Ares V launches from Kennedy Space Center in Florida. Following booster separation and core staging, the EDS ignites at altitude and places the vehicle into a stable parking orbit. Shroud separation occurs following EDS ignition to avoid shroud re-contact with the vehicle. The Orion crew vehicle, launched by the Ares I, rendezvous and docks with the Altair. Following system checkouts, the EDS reignites and performs a trans lunar injection (TLI) burn to send the combined vehicles toward the Moon. The EDS is discarded en route, completing the Ares portion of the lunar mission. The current concept of operations calls for an Ares V launch as early as 90 minutes after Ares I, with 3 subsequent launch opportunities over the next 3 days. Ares V is currently designed for a 4-day loiter, with TLI on the fourth day.
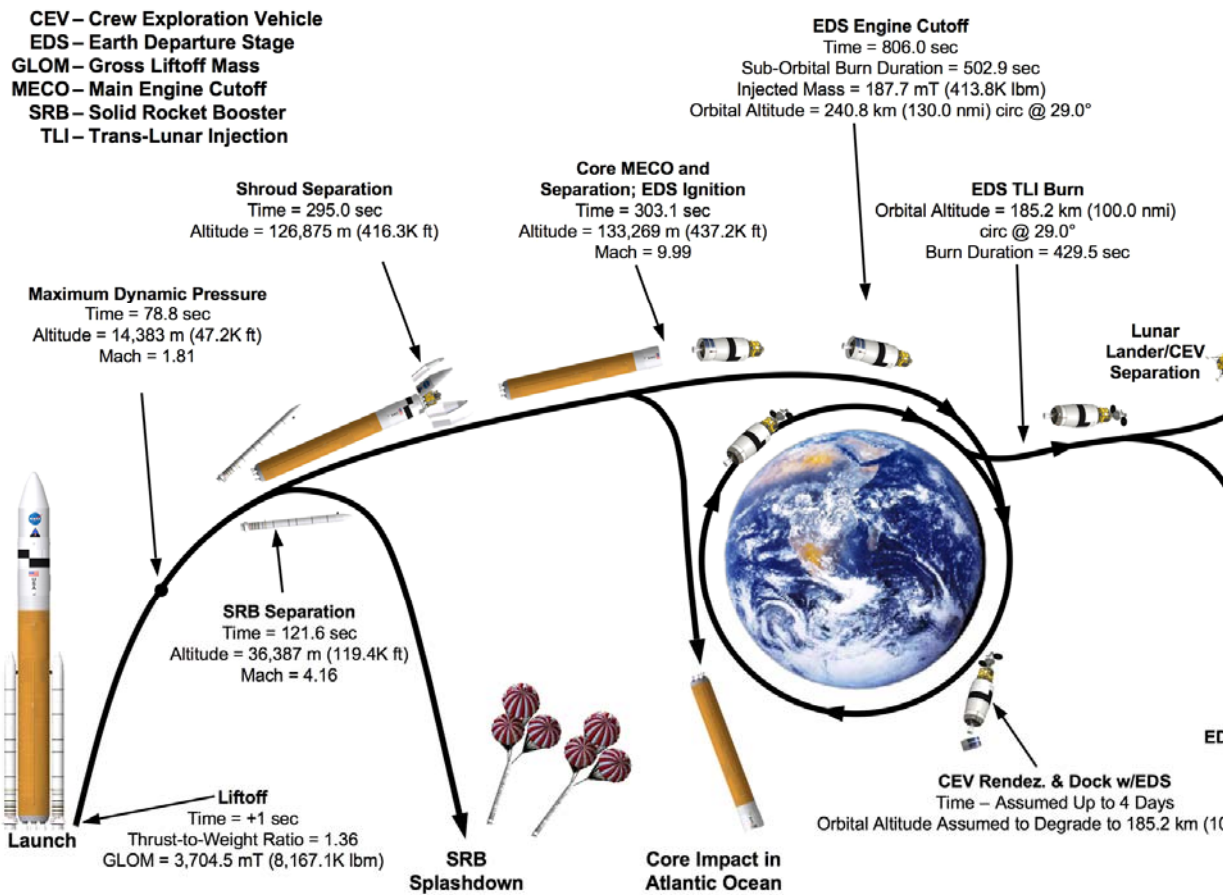

Fig. 4: Ares V profile for the dual-launch design reference mission lunar sortie.

III. Early Hardware Progress and Initial Design Work

Ares V remains in a pre-design analysis cycle stage pending a planned late calendar 2010 ATP. The Ares Projects continue to refine the Ares V design through a variety of internal studies. In addition, Ares V benefits from the decision to use heritage hardware as a point of departure and from the goal to seek commonality with Ares I. The following sections will discuss the major components of the Ares V launch vehicle and their technical status.

A. Ares V Core Stage

Despite the focus on Ares I as a Space Shuttle replacement for ferrying crews to the International Space Station, seed money from Congress allowed NASA in 2006 to examine the changes required in the Pratt & Whitney Rocketdyne (PWR) RS-68 engine (Figure 5) to meet NASA requirements for lunar exploration. The Air Force is already planning upgrades that include redesigned turbine nozzles to increase maximum power and a main injector with additional elements to improve specific impulse and thrust. This variant is designated the RS-68A. The NASA version, designated RS-68B, would go further by increasing the operational life of the ablative nozzle. It would also include a redesigned helium spin start duct and turbine seals and start sequence changes to minimize helium usage and pre-ignition of free hydrogen around the vehicle and launch pad.

A seal test rig is being built at Marshall Center to test an intermediate seal re-design expected to reduce helium usage. Helium spin start testing on the engine is planned for later this year at Stennis Space Center. PWR proposes designing and building a development gas generator and helium spin start duct based on the seal test results and also bringing the design of a segmented carbon ring seal to critical design review level, allowing for testing at MSFC. If completed before ATP, these efforts will save a year in schedule, and will allow the Main Propulsion Test Article (MPTA) engines to be delivered on time.
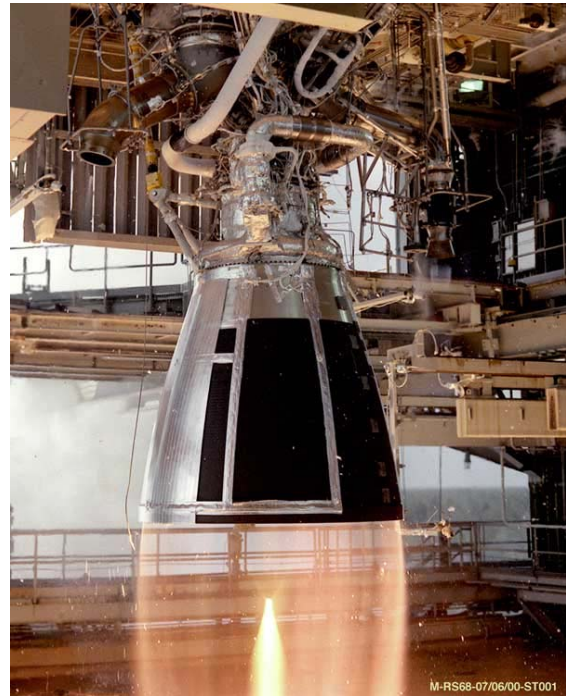

Fig. 5: RS-68 during testing.

A Core Stage engineering study is now under way as part of the Ares V Integration Study. The basis for this study is the LCCR POD, which increased the key dimensions of the stage. The hydrogen tank was increased 13.3 feet in length beneath the SRB cross-beam support. To maintain the required engine mixture ratio and accommodate the longer SRB, the LOX tank was stretched 4.9 feet above the SRB crossbeam attachment. The stage now measures 233.9 ft (71.3 m) in length and 33 feet (10 m) in diameter.

A key element is configuring the stage for six RS-68B engines in relation to the adjacent SRBs. Multiple geometries are being considered including the two geometries shown in Figure 6 on the following page.
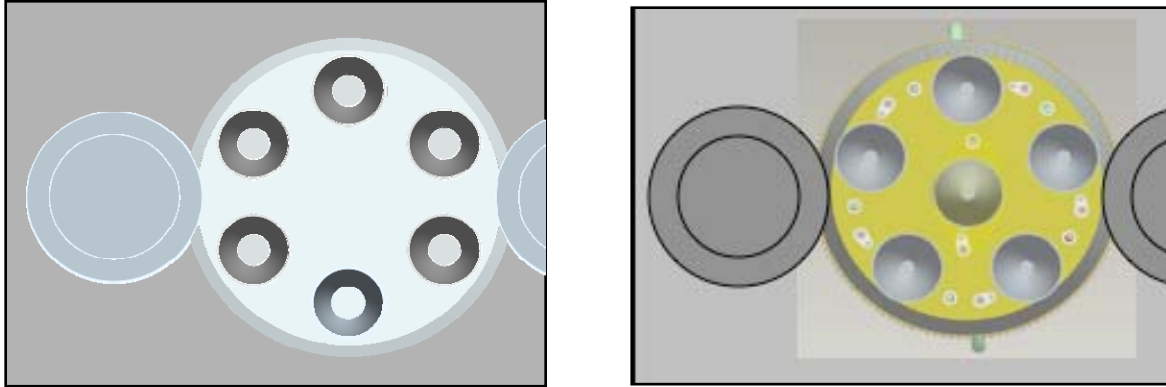
Fig. 6: Options for six Core Stage RS-68 engines are 6 in a circle, left, and 5 around 1, right.

Plume-induced base heating caused by the main engines and boosters is a primary consideration in that design, both on the launch pad and during ascent. For Ares V, the base heating environment is increased by RS-68B turbine exhaust re-combustion and by the turbine exhaust impinging directly on the RS-68B nozzles. Affected surfaces and components likely will require some level of thermal protection, given the expected severe heating environment. The close spacing of the RS-68B engines also will create strong interaction shocks. Maximum RS-68B nozzle radiation is approximately 3 times that recorded from the F-1 engine nozzles on the Saturn S-IC stage. RS-68B turbine exhaust re-combustion adds significant energy to the base flow field and convective heating rates throughout first stage ascent. Radiation on the boosters' inboard-facing surfaces from the RS-68B plumes and the opposing booster plume are about the same as what is experienced on the Space Shuttle. However, convective heating on the inboard facing surfaces of the thermal curtain aft skirt is higher than Shuttle heating due to RS-68B plume interaction reverse flow and lateral flow out of the Core Stage base. An example of plume induced flow separation on a Saturn V ascent is shown in Figure 7 below.

Upcoming activities at the time of this paper were performance of weight estimates on the core stage, definition of the base thermal environment, loads and key structural weight, evaluation of thermal protection, layout of the thrust structure, and updating the controllability assessment to determine engine gimbal requirements, including gimbal with fixed booster nozzles.
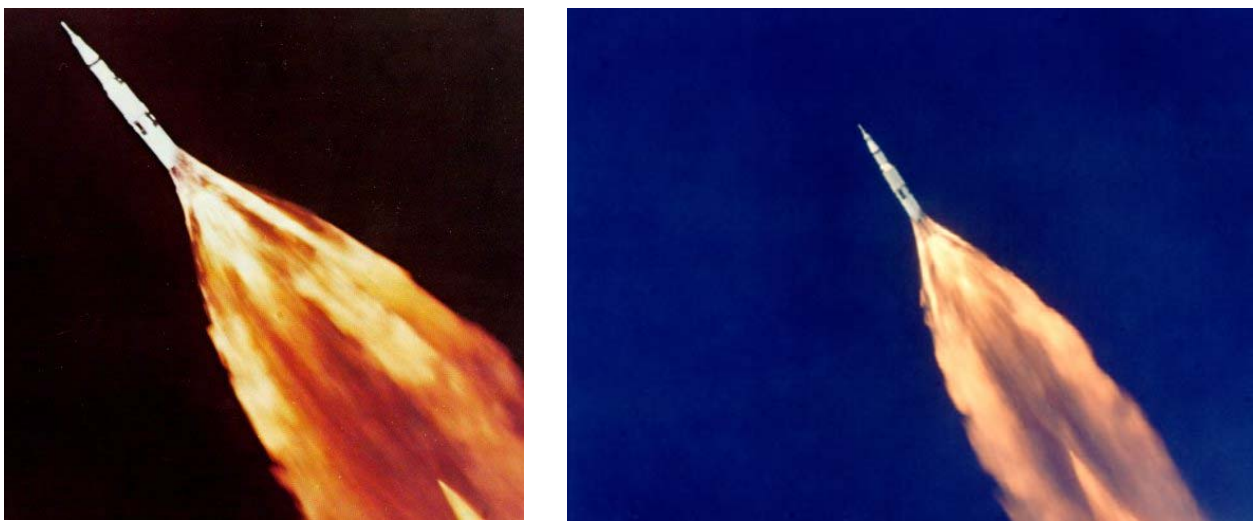

Fig. 7: Two views of Apollo Saturn V plume-induced flow separation.

B. First Stage Solid Rocket Booster

The Ares V first stage booster is derived from the current Space Shuttle 4-segment steel case solid rocket booster (SRB) and makes use of the same designs, manufacturing facilities, tooling, and experienced workforce. The current design is illustrated in Figure 8.

The booster consists of five normal-sized booster segments and one half segment, which contains 119,450 pounds (54,181 kg) of added propellant and field joints on both ends. The booster uses the same heritage PBAN propellant used by the Shuttle boosters and the Ares I first stage. The Ares V booster is approximately 160 inches (4m) longer than the Ares I 5-segment booster design. The design increases total propellant weight and permits a longer Core Stage with additional Core Stage propellant. The design uses heritage steel case cylinders and domes, as well as aft skirt, forward skirt, frustum, and nose cone. The core stage-to-booster attach cylinder of the aft segment and the attach ring/struts are assumed to be Shuttle RSRB heritage. The case design maximum expected operating pressure is the same as the Shuttle RSRM and Ares I booster design. To achieve the same operating pressure, the nozzle throat diameter was widened five inches (0.127 m) larger than the current Shuttle booster. The widened throat enables more propellant to be expelled at the same pressures as the Shuttle Redesigned Solid Rocket Motor (RSRM). The Ares V boosters are designed to be recovered. The Ares I SRB, which will be repurposed for the Ares V first stage booster is making progress as well. A nozzle process simulation article (PSA) has been fabricated and test fitted, main parachutes for the first flight test have been fabricated, new insulation has been installed n a PSA demonstration motor, and data from Shuttle solid rocket motor test firings (Figure 9) are being used to inform the Ares I design.

Preparations intensified this year for the Ares I-X test flight, which will demonstrate staging and separation, vehicle and roll control, aerodynamics, first stage entry, and ground operations at Kennedy Space Center. Technologies and manufacturing tools for the Ares I Upper Stage are being developed and installed at Marshall Space Flight Center (MSFC). These tools, including a friction stir welding process and a new vertical weld tool, eventually will be used for the Ares V EDS as well. Upcoming work planned includes upgrading the performance predictions for the 5.5-segment steel case configuration, optimizing the 5.5-segment steel case grain design to maximize Ares V vehicle performance, and estimating the maximum expected thrust imbalance between the boosters during steady-state and tail-off segments of the burn.
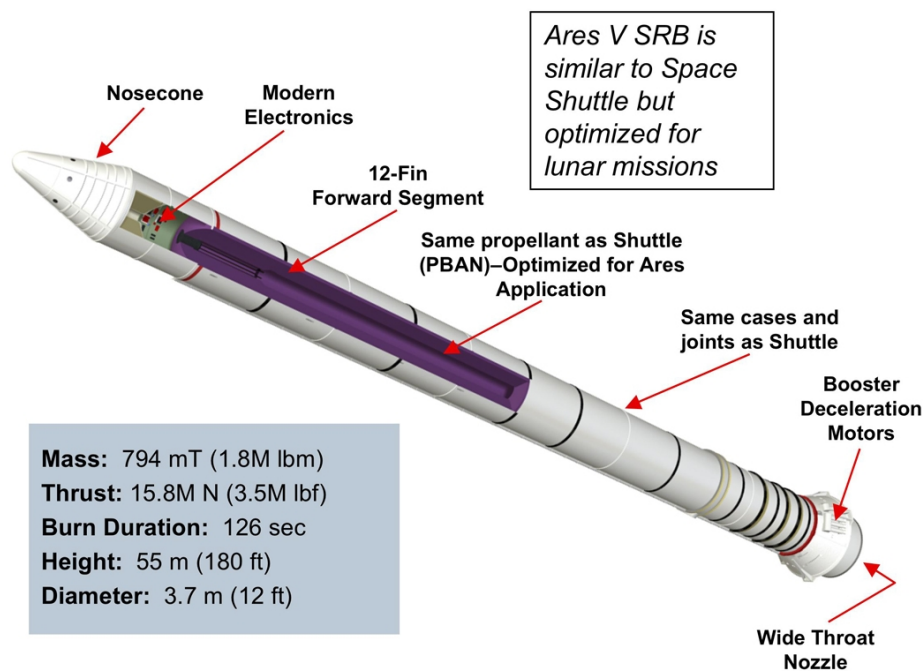

Fig. 8: .5-segment SRB for Ares V.

Fig. 9: Ares I solid rocket motor test firing in Utah.

C. Earth Departure Stage

Glenn Research Center began a series of EDS design trades and analyses in 2007. Many subsystem and system assessments are ongoing and have been incorporated into the Ares V Integration Study. Since LCCR approval of the new Ares V POD, these studies reflect a stage lengthened by 2.4 feet to 76 feet. When they began, the EDS studies sought structural changes to increase payload and better understand and optimize on-orbit power requirements, insulation to prevent propellant boil-off during loiter, and micro-meteoroid/orbital debris (MMOD) protection required for on-orbit loiter. Studies also considered interactions with and support to the Altair lander, including providing power from solar arrays, batteries or fuel cells.

The baseline EDS for the pre-LCCR studies comprised a 33-foot-diameter stage with metallic structures capable of delivering a 106,000-pound Altair to LEO and supporting a 4-day loiter period. Several methods of reducing weight were considered, included using composite materials, lighter structures; eliminating structure by using nested, conformal, and common bulkhead tanks; dual use of structures as MMOD protection; reducing consumables; transferring weight from the EDS to the Core Stage; and jettisoning loiter hardware such as MMOD protection, power, insulation, and expended propellant tanks prior to the TLI burn. The study found that the EDS needs 1 pound of propellant for every 0.8 pounds delivered to LEO and every 1.1 pounds delivered to TLI. As tank shapes studied moved away from spherical, they increased in surface area and therefore tank weight, insulation, MMOD protection, and boil-off. Shortening the interstage provided 1 pound of mass for every 2 pounds of interstage reduced. Jettisoning 2.2 pounds of equipment before TLI provided 1 more pound of payload to TLI. The effort concluded that no single option can provide the desired allowance for a lander of up to 119,000 pounds. Eliminating the 3,000-pound intertank using nested, conformal or stretched LH_2 tank (Figure 10) delivered no net mass benefit. Most payload improvement was created by moving from metallic to composite materials.
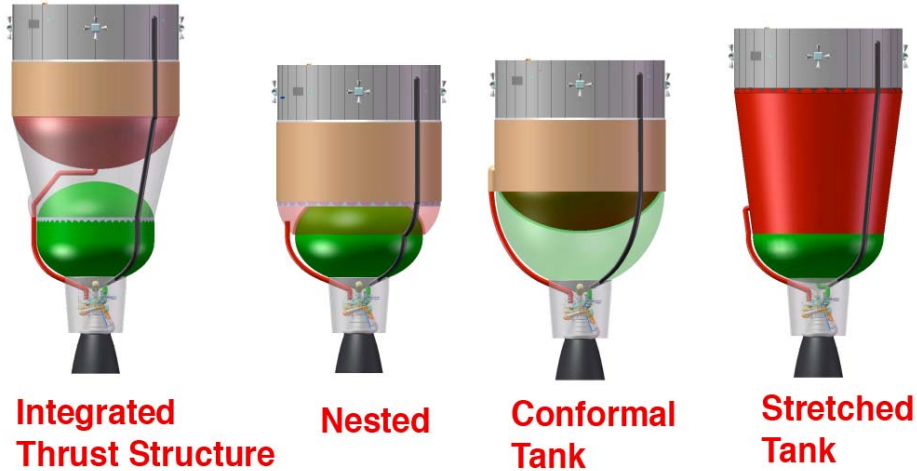
Fig. 10: Alternate structural configurations traded.

By combining the effects of composite dry structures, an integrated thrust structure, and a jettisonable loiter kit, total TLI payload increased to 110,892 pounds. An all-composite stage increased performance to 114,640 pounds but carried technical issues related to material properties, manufacturing, LOX compatibility, LH_2 permeation, damage tolerance, bonding and joining efficiency, and reliability. Due to their high complexity and cost, options such as composite propellant tanks and jettisonable tanks (Figure 11) are being held in reserve until refined Core Stage designs and Altair integration assessments show a need for these measures.

The EDS study resulted in a recommended baseline cargo EDS configuration (Figure 12), with several possible loiter kits for crewed EDS missions requiring rendezvous with Orion before TLI. The loiter kits could be jettisoned as appropriate before the TLI burn to improve payload performance. Loiter kits would include MMOD protection, boil-off insulation, an MMOD loiter skirt surrounding the J-2X engine containing fuel cells, reaction control system (RCS) propellant, and different configurations of batteries and fuel cells for the loiter skirt and forward skirt. The 5-hour cargo loiter period required significantly less power than the 4-day crewed loiter period. The crewed loiter kit provided 111,000 pounds of payload – 8,000 pounds short of desired performance. The cargo EDS provided 138,000 pounds of payload, a surplus of more than 5,000 pounds over the requirement, generating a question for possible future study on whether some of the 5,000 pounds shortfall for crewed missions could be moved to a cargo flight.
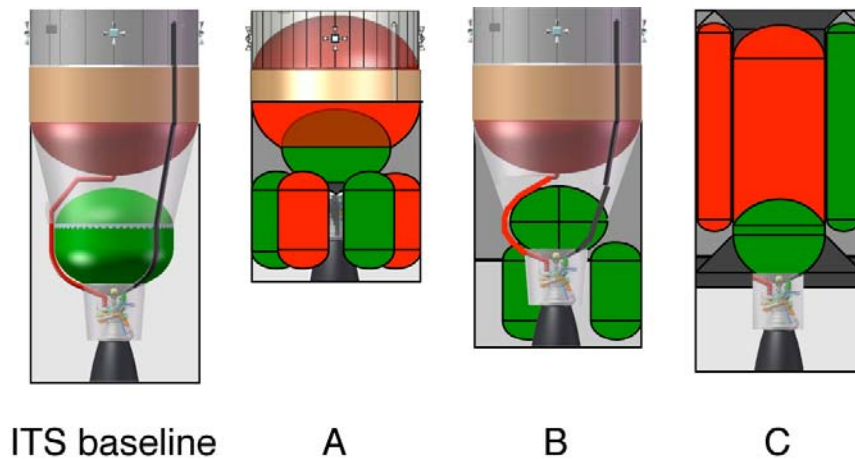

Fig. 11: Shown with the integrated thrust structure baseline, left, are drop tank concepts: A. all ascent LO_2 and 1/3 TLI LH_2 drop tanks; B all ascent LO_2; and C all ascent LO_2 and LH_2.

Usable Propellant: 251.9 t (555.2k lb$_m$)
Dry Mass: 24.2 t (53.5k lb$_m$)
Burnout Mass: 26.6 t (58.7k lb$_m$)
Number of Engines: 1
Engine Type: J-2X

- Aluminum-Lithium (Al-Li) propellant tanks
- Composite dry structure
- 10 m (33 ft) outer diameter
- Derived from Ares I Upper Stage
- 4-day on-orbit loiter capability prior to Trans-Lunar Injection (TLI)
- Maintains Orion/Altair/EDS stack attitude in Low Earth Orbit prior to TLI Burn
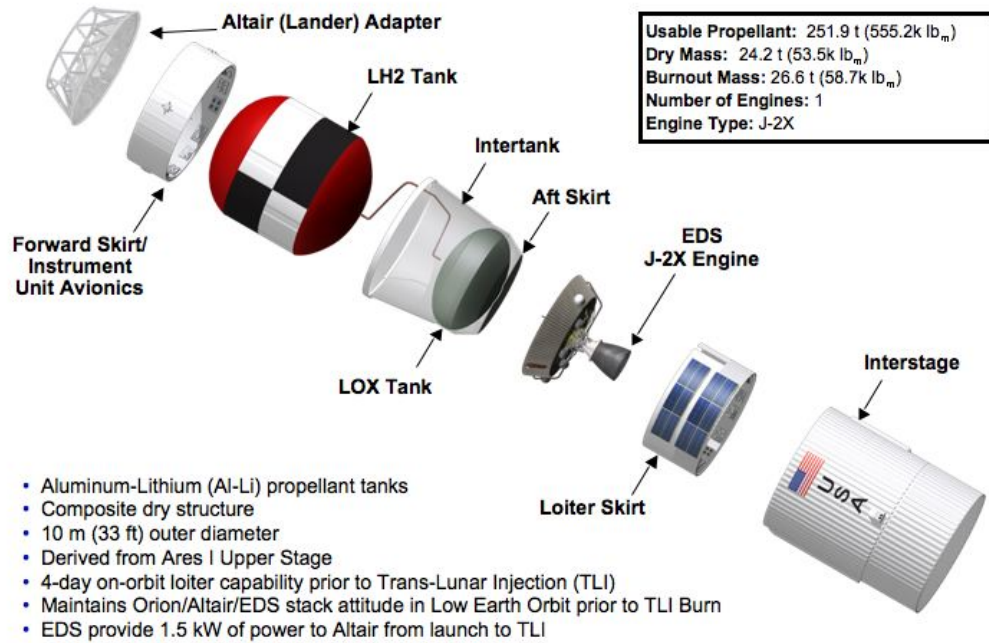- EDS provide 1.5 kW of power to Altair from launch to TLI

Fig. 12: Expanded view of 10-meter EDS structure including Interstage.

The EDS study also examined MMOD protection, propulsion and power subsystems, on-orbit loiter issues, and power options.

The power subsystem evaluation concluded that solar arrays are best for loiter periods of longer than 7 days. For less than 7-day periods, dedicated fuel cells are better than solar arrays because fuel cells have comparable or less mass, no deployment issues, and insensitivity to attitude as compared to solar arrays, which require reaction control system (RCS) fuel to maintain solar orientation for maximum power generation. Battery options are only feasible for time periods less than 10 hours. Boil-off fuel cell types seem more mass-competitive than dedicated fuel cells or solar arrays. However, their complexity makes them less desirable. The study concluded that using the Altair fuel cells in combination with reactants stored in the EDS tanks to provide EDS power showed more promise and merited further investigation. Space Shuttle fuel cell tanks might have been used but were ruled out by commonality considerations. Altair and lunar base systems are based on Proton Exchange Membrane (PEM) fuel cells, which are lighter and produce less heat than the Space Shuttle fuel cells. The EDS cargo option had

more batteries than the crew loiter option due to the difference in mission duration and power levels.

The propulsion subsystems were evaluated based on preliminary configurations for both baseline and drop tank main propulsion system (MPS) configurations and the RCS configuration. Studies generally concluded that redundancy levels needed to be examined in greater detail for trade configurations and that better information on large components was required and should be incorporated into the models. The propulsion evaluation also noted that the EDS design faces unique challenges for its in-space restart, including long-term operation of pneumatic control, long-term storage of cryogenic propellants, use of an O_2/H_2 burner, and long-term operation of thrust vector control (TVC) in space. An evaluation of cryogenic systems concluded that separate tanks were preferable because common bulkhead heat loads were too high for missions longer than a few days. Multilayer insulation (MLI) was the only viable insulation for MMOD protection for missions greater than a few days. The evaluation also recommended using pulse flow instead of a recirculation pump to eliminate heavy hardware and reduce heat loads using RCS settling instead of ullage motors, and settling the propellant intermittently instead of using

continuous settling for mission durations of more than a few hours.

Several insights emerged from an analysis of LEO loiter orbital decay and attitude. The results were shaped by limits on Orion's rendezvous altitude, rendezvous window durations, power shortfalls, and orientation needs. As a result, the study concluded that launching to a higher altitude and accepting drag even for worst-case EDS orientations was preferred to rebooting the EDS during loiter. The stack loiter attitudes (Figure 13) studied included gravity gradient with Orion facing zenith, Local Vertical Local Horizontal (LVLH)with Orion in front, sun-pointing with the Orion main engine facing the sun, and XPOP inertial with the stack's long axis pointing out of plane and Orion's main engine primarily facing the sun. The XPOP attitude option experienced the greatest orbital decay. The gravity gradient orientation was identified as the preferred option because it requires the least amount of propellant. With an insertion altitude of 130 nautical miles to avoid the need for reboost, orbital decay is slow enough to meet rendezvous and TLI goals. This preference for a 130 nautical-mile LEO insertion altitude presented a challenge because the Orion design is based on a 160 nautical-mile insertion altitude. Efforts are being made to resolve the discrepancy in the insertion altitude.

D. J-2X Upper Stage Engine

The J-2X altitude-started engine is now in development for the Ares I upper stage. The J-2X is designed to retain the J-2 engine's simpler gas generator cycle, yet provide both higher thrust and higher efficiency than its Saturn-era predecessor. This will help J-2X meet the greater Constellation performance demands and meet the goal of commonality by powering both the Ares I Upper Stage and the Ares V EDS. The gas generator, main controller, main injector and main combustion chamber are derived from the current RS-68 engine design. Turbomachinery and ducts are based on the J-2S development in the 1970s.

The J-2X is required to operate in primary or secondary modes. In primary mode for the Ares I, it will provide 294,000 pounds of thrust. In secondary mode for the Ares V, it is designed to operate at 242,000 pounds of thrust by changing the propellant mixture ratio from 5.5 to 4.5. This requirement is the result of an effort to lower the loads on the docking system between the mated Orion and Altair vehicles. Because Ares V requirements remain in a state of flux, engine development now is focused on the Ares I mission. Changes for the Ares V mission, particularly the loiter/vacuum start requirement, will have to be incorporated into the engine via a kit-type modification. The current J-2X configuration is illustrated in Figure 14.
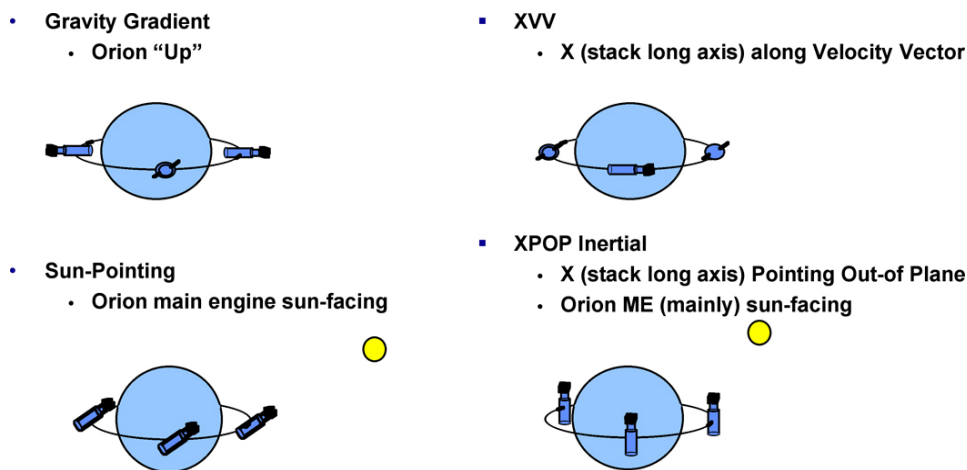

Fig. 13: Stack loiter attitudes assessed at 0, 30, and 52 degrees beta.

Fig. 14: The J-2X Upper Stage Engine for the Ares I and Ares V.

The J-2X reached critical design review (CDR) this fall ahead of other elements due to an aggressive schedule, which anticipates problems typically experienced in an engine development program. Heritage J-2 powerpack hardware – comprising mainly heritage turbomachinery and gas generator – was test fired 6 times in 2008, accumulating more than 1,300 seconds of operating time at power levels up to the equivalent of 274,000 pounds thrust required for Ares I. (Figure 15)

The tests resolved differences between the heritage turbopump performance data and recent component-level tests, assessed potential "pogo" issues, and investigated scissors duct performance. A workhorse gas generator underwent testing at MSFC this year to demonstrate components before contract selection of configuration, chamber length and injector element pattern. Cold flow testing to simulate nozzle side loads at MSFC resulted in a better predictive model that will allow nozzle weight to be minimized. Tests of subscale J-2S fuel and oxidizer turbopump inducers are assisting with the final blade design. Heritage fuel- air turbine testing in 2008 will anchor computer fluid dynamics modeling and map turbine performance over a range of operating conditions. Early manufacturing is already underway, with inertial welding demonstrations for turbine disk and shaft machining on the oxidizer turbopump (OTP), casting trials for the OTP discharge volute housing, main combustion chamber forward manifold, and spinning of the main combustion chamber liner.
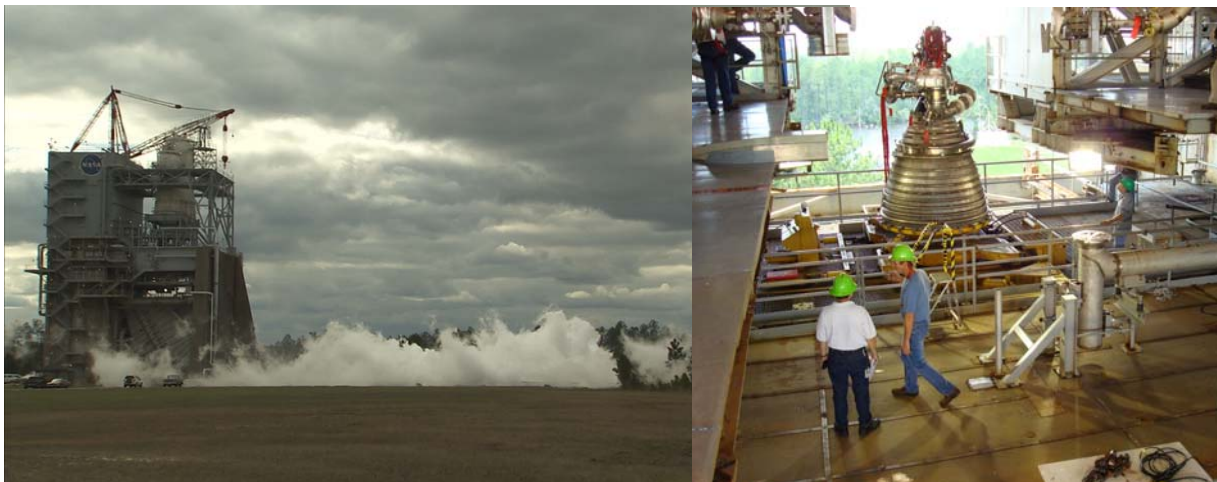

Fig. 15: Successful second powerpack test (left) and powerpack removal from stand (right).

To support J-2X testing, the A-1 test stand at Stennis Space Center, Mississippi, is already performing the previously mentioned powerpack tests. The A-2 test stand will be turned over from the Space Shuttle Main Engine program to J-2X in July 2009 and begin testing in April 2010. Construction is also under way for the new A-3 test stand at Stennis, which will begin supporting simulated altitude testing in 2010.

E. Payload Shroud

A payload adapter atop the EDS will support the Altair payload within the largest payload shroud ever built. Designed to carry the Altair lunar lander or other large volume payloads, the usable volume beneath the shroud, shown in Figure 16, is nearly three times larger than the current Space Shuttle payload bay volume. As a real-world example of its mass and volume capabilities, the Ares V could launch 8 fully loaded school buses into Earth orbit as shown below – with mass capability to spare.

A shroud study team began work in 2007 to develop an initial concept and weight estimate for future trades and a basis for shroud development costs. The team's point of departure (POD) shroud was a biconic shape, with four petals, composite sandwich construction, and with a painted cork thermal protection system (TPS) bonded to an outer face sheet. The design also included the payload environmental control system, avionics, and separation system. Analysis included geometry definition, aero-pressures at critical loads, aero-acoustics at transonic Mach numbers, aero-heating along the flight profile, TPS sizing, structures sizing and subsystem mass estimation for acoustic blankets, separation systems, etc. Further studies continued to examine shroud geometry, structure material temperature limit, and TPS materials, structural architecture, manufacturing, shroud separation, and load sharing with the lunar lander.

The studies determined a number of key findings, including: the small base flair on the POD caused a significant pressure spike at max Q; acoustic levels can be reduced using a smooth ogive nose shape; use of spray-on foam insulation (SOFI) could reduce TPS mass substantially relative to cork; and a global buckling check indicated a positive but low margin of safety. A subsequent analysis cycle took a closer look at drag, acoustics, and other aspects of the biconic POD to achieve the best payload performance. Options referred for wind tunnel testing are shown in Figure 17.
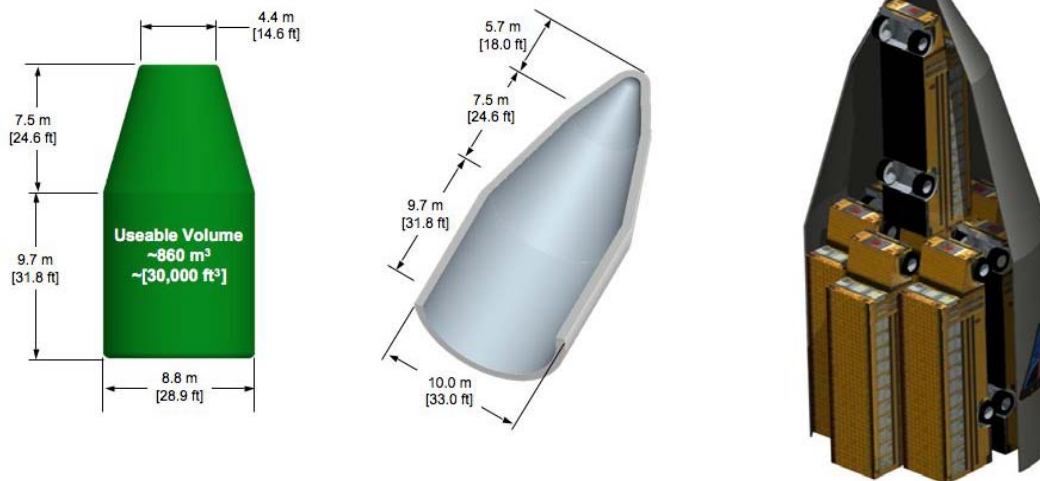

Fig. 16: Ares V payload shroud outer dimensions and usable volume are shown (left) and in comparison to the number of 33-foot-long school busses – 8 – that could be contained inside.
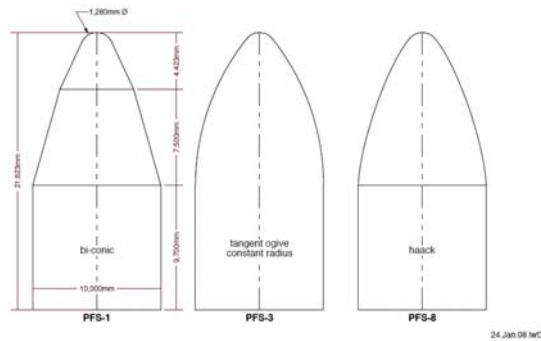
Fig. 17: Payload shroud shapes delivered to
MSFC to support wind tunnel tests.

To date, studies show overall sound pressure level in the shroud region of 153 decibels. The heating environment is relatively benign. Assuming uniform TPS thickness, total TPS weight is 2,991 pounds. By using SOFI instead of cork, TPS mass potentially could be reduced by 46-80 percent of TPS mass. An analysis of shroud separation (Figure 18) assumed using a frangible joint for horizontal separation and thrust rails for vertical separation, as well as a 0.4 g vehicle acceleration after Core Stage separation and EDS ignition. Additional analysis will examine contact forces at the base of the fairing and simulate other design options such as hinges and push-off springs.

Future work will continue on shroud geometry trades, updated vibro-acoustic analysis and an update of acoustic blanket masses, alternate structural approaches, manufacturing trades related to autoclave

size, and using the shroud for structural support of the lander during ascent.

IV. Performance and Capabilities

The result of the many analyses and trade studies is vehicle of unprecedented capability. Ares V frees payload designers from current constraints on mass and volume or to vastly simplify the design and packaging of spacecraft to realize greater cost efficiency. Ares V combined with Ares I can lift 71 mT to TLI – 58 percent more than the Saturn V, or 62.8mT in single launch mode – 40 percent greater than Saturn V. The current point-of-departure shroud contains a usable volume of approximately 860 cubic meters (30,371 cubic feet). Internal analysis also examined a longer shroud with a usable volume of approximately 1,020 cubic meters (36,000 cubic feet). The maximum barrel length is constrained by the Kennedy Space Center Vehicle Assembly Building height. The increased length also introduces a theoretical payload reduction of 200 kg.

Ares V performance for Concept 51.00.39 was analyzed for four selected mission profiles of interest to scientific, commercial, and national security users – a Sun-Earth Lagrange Point 2 mission, geosynchronous transfer orbit, geosynchronous Earth orbit, and a lunar outpost cargo reference mission. Payload performance for those destinations is presented in Figure 19 below. LEO performance for the new 51.00.48 POD is expected to exceed the values shown. The performance analysis for the new POD will be updated later.
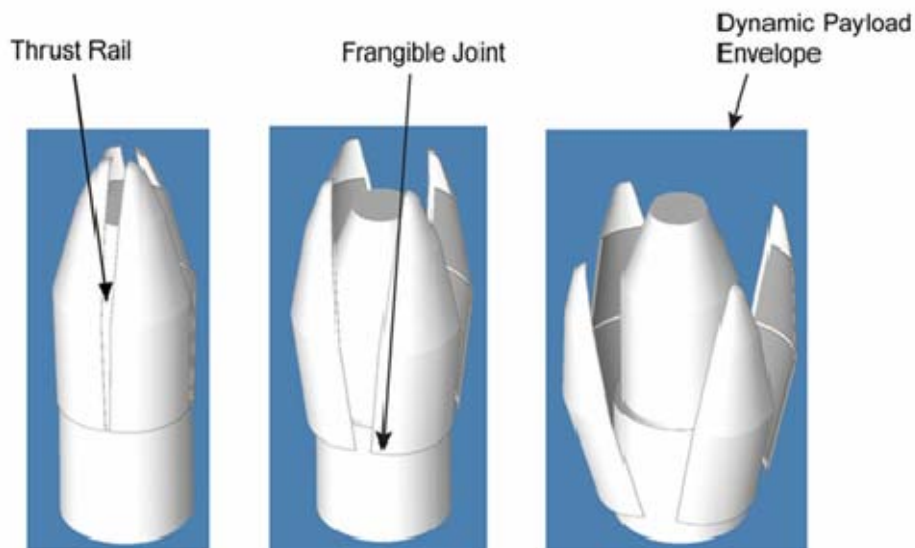

Fig. 18: Payload shroud separation rigid body analysis.

Mission Profile	Target	Constellation POD Shroud		Extended Shroud	
		Payload (lbm)	Payload (t)	Payload (lbm)	Payload (t)
1) Sun Earth L2	C3 of 0.7 km²/s²	123,100	55.3	121,800	55.1
2) GTO Injection	Transfer DV 8,200 m/s	155,700*	70.3*	153,730*	69.7*
3) GEO	Transfer DV 14,100 m/s	79,700	36.2	78,730	35.7
4) Cargo Lunar Outpost (TLI Direct), Reference	C3 of -1.0 km²/s²	125,300	60.3	123,700	60.1

Fig. 19: Ares V performance for selected missions, comparing POD and extended shrouds

V. Forward Work

While studies continue with the point-of-departure configuration approved during the LCCR, the Review also endorsed continuing to investigate the option for using composite case boosters and HTPB propellant. Studies continue on Ares V booster options with investigations of structure and thrust issues related to increased booster length, as well as nozzle options of different lengths, throat diameters, expansion ratios, and performance. Additional work is under way or planned to understand:

- cryogenic fluid management
- manufacturing
- processing and logistics of large composite structures
- EDS LEO loiter issues
- attitude control
- injection altitude
- power supply to Altair
- and risk, cost estimating and reliability.

Manufacturing space at Michoud Assembly Facility is being assessed to include the impact of a 40-foot autoclave and a new shroud manufacturing area. Issues associated with integrated testing are under study, including the location for a large scale cryo-structural test facility, conversion of the A-2 test stand at Stennis Space Center for EDS testing, EDS orbital simulation testing, development of an integrated test schedule, and an EDS test and verification plan.

Budgeting and scheduling to support a late 2010 ATP, logical development, and a 2018 first flight A summary schedule of Ares V development plans leading to the first series of launches is shown in Figure 20. The Ares Projects are also reaching out to the academic and government community for science and military missions that may benefit from the Ares V capabilities, specifically space-based astronomy missions to the outer solar system and beyond.

NASA design of the Ares V is evolving to support the evolving design of the other elements of the lunar exploration architecture, provide the Earth to orbit transportation and the trans lunar propulsion for the crewed and cargo landers loaded with habitats, vehicles, power supplies, scientific equipment, in-situ resource development hardware necessary to live, work and explore another world. It will be as technically and operationally safe, simple, and affordable as current technology can make it. NASA's focus for Ares V is the lunar mission. But Ares V's heavy lift capability will immediately provide a national asset that can support a number of potential government and commercial ventures. The Ares V team will continue to support evolving Constellation architecture requirements with the knowledge that the work today is preparing a future launch pad for unprecedented exploration of Earth's closest neighbor and destinations beyond.
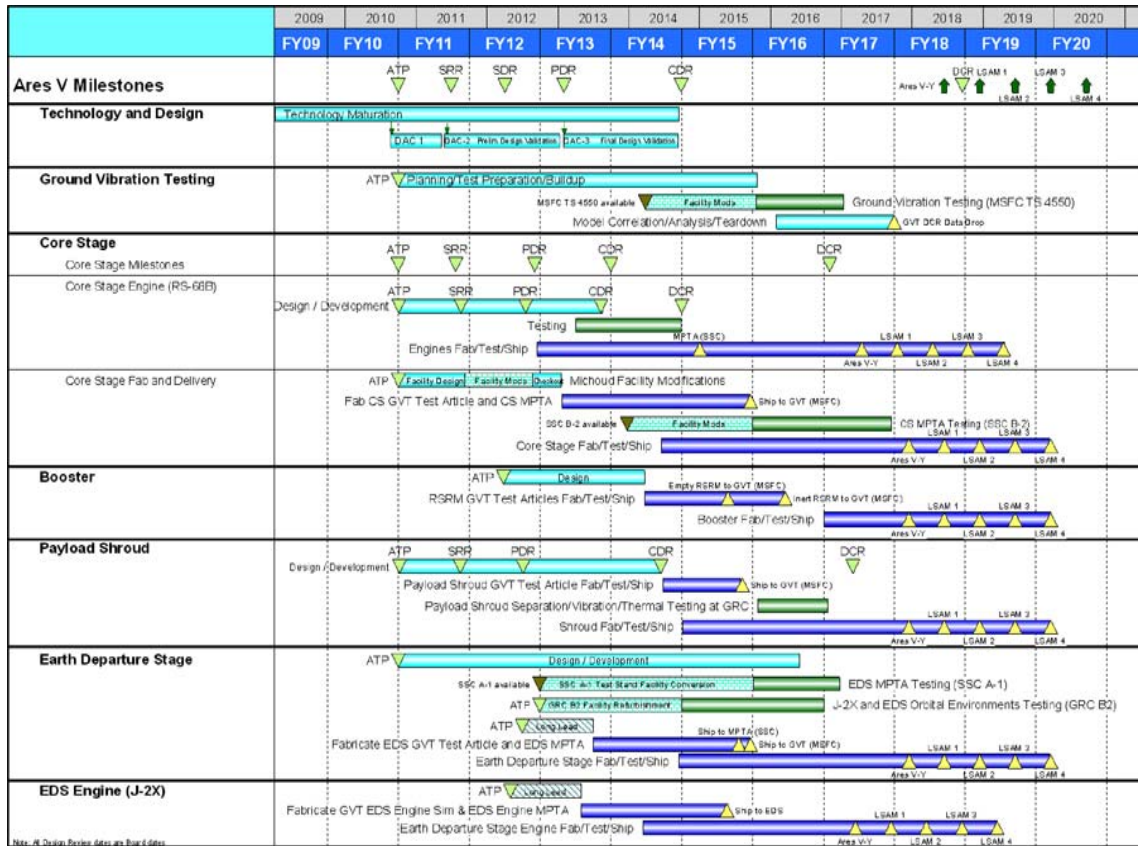
Fig. 20: Ares V summary schedule.