

## **A New Heavy-Lift Capability for Space Exploration: NASA's Ares V Cargo Launch Vehicle**

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### **Abstract**

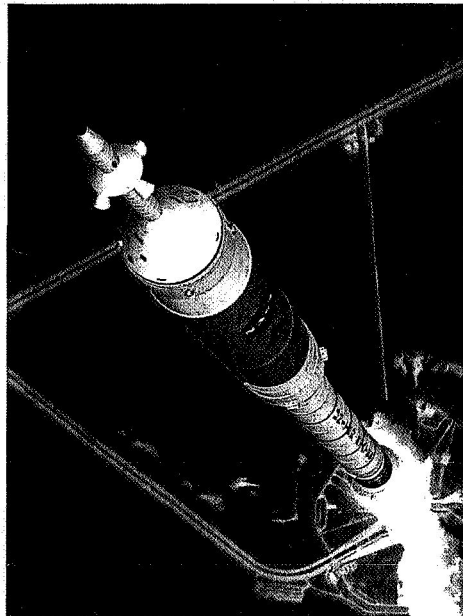
The National Aeronautics and Space Administration (NASA) is developing new launch systems in preparation for the retirement of the Space Shuttle by 2010, as directed in the United States (U.S.) Vision for Space Exploration. The Ares I Crew Launch Vehicle (CLV) and the Ares V heavy-lift Cargo Launch Vehicle (CaLV) systems will build upon proven, reliable hardware derived from the Apollo Saturn (1961 to 1975) and Space Shuttle (1972 to 2010) programs to deliver safe, reliable, affordable space transportation solutions. This approach leverages existing aerospace talent and a unique infrastructure, as well as the vast amount of legacy knowledge gained from almost a half-century of hard-won experience in the space enterprise. Beginning early next decade, the Ares I will launch the new Crew Exploration Vehicle (CEV) to the International Space Station (ISS) or to low-Earth orbit for trips to the Moon and, ultimately, Mars. Late next decade, the Ares V's Earth Departure Stage will carry larger payloads such as the lunar lander into orbit, and the Crew Exploration Vehicle will dock with it for missions to the Moon, where astronauts will explore new territories and conduct science and technology experiments. Both the Ares I and Ares V systems are being designed to support longer future trips to Mars. The Exploration Launch Projects Office, located at NASA's Marshall Space Flight Center, is designing, developing, testing, and evaluating both launch vehicle systems in partnership with other NASA Centers, Government agencies, and industry contractors. This paper provides top-level information regarding the genesis and evolution of the baseline configuration for the Ares V heavy-lift system. It also touches on risk-based-management strategies, such as building on powerful hardware and promoting common features between the Ares I and Ares V systems to reduce technical, schedule, and cost risks, as well as development and operations costs. Finally, it gives a summary of several notable accomplishments over the past year, since the Exploration Launch Projects effort officially kicked off in October 2005, and looks ahead at work planned for 2007 and beyond.

## I. Introduction

The strategic goals outlined in the U.S. Vision for Space Exploration (January 2004) guide NASA's challenging missions of scientific discovery.<sup>1</sup> In addition, the U.S. Space Transportation Policy (December 2005) directs America's civil space agency to provide launch vehicle systems for assured access to space.<sup>2</sup> The Vision provides specific guidelines for relatively near-term human exploration of the Moon to prepare astronauts for longer journeys to Mars. It also commits the United States to completing the International Space Station and retiring the Space Shuttle by 2010. New space transportation systems will provide new capabilities for the human exploration of space beginning as soon as possible after the Shuttle is retired.

In the 18<sup>th</sup>, 19<sup>th</sup>, and 20<sup>th</sup> centuries, visionary pioneers conquered the land, sea, and air. While NASA works in cooperation with its international partners to complete the Space Station as an essential part of learning to live and work productively for long periods away from Earth's protection, the Agency anticipates that mastering space in the 21<sup>st</sup> century will be an international effort, as well.<sup>3</sup> Mobilizing resources to set up a permanent outpost on the Moon and to make forays to Mars will be a cooperative effort that binds countries together for the peaceful pursuit of space exploration, much as the International Space Station partnership has opened doors for long lasting alliances connecting spacefaring nations.

The Ares I Crew Launch Vehicle (see Figure 1) is slated to fly the Crew Exploration Vehicle by 2014, and the Ares V Cargo Launch Vehicle (see Figure 2) is slated to fly the Lunar Surface Access Module (LSAM) by 2020. These systems are being designed for safe, reliable, and sustainable space transportation by building on a foundation of legacy knowledge and heritage hardware, while reflecting modern engineering and business best practices that meet stringent standards and deliver maximum value for the investment. Together, these space transportation systems will replace the Space Shuttle for the human exploration of Earth's cosmic neighborhood and beyond.



**Figure 1. Ares I launch concept.**

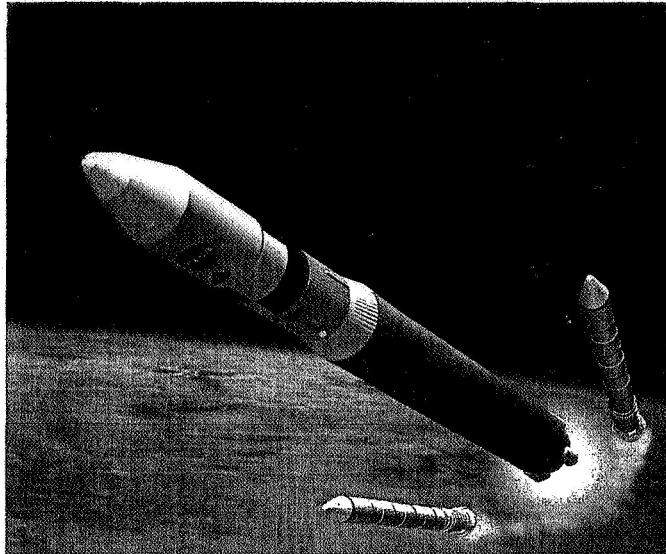


Figure 2. Ares V launch concept.

The Crew Launch Vehicle has been named Ares I and the Cargo Launch Vehicle has been named Ares V, after the ancient Greek name for Mars, anticipating the launch vehicles' ultimate destination. The "I" and "V" designations pay homage to the Apollo Saturn I and Saturn V launch vehicles that first enabled humans to land on the Moon in the late 1960s. As is shown in Figure 3, the Ares V launch vehicle has similar mass and performance characteristics as did the Saturn V, with the obvious difference being the lack of a crew capsule payload. Through years of triumph and tragedy, direct experience and engineering risk analyses have concluded that separating the crew from the cargo during launch reduces safety risks and improves safety statistics. The planned exploration architecture discussed below takes into account that information.

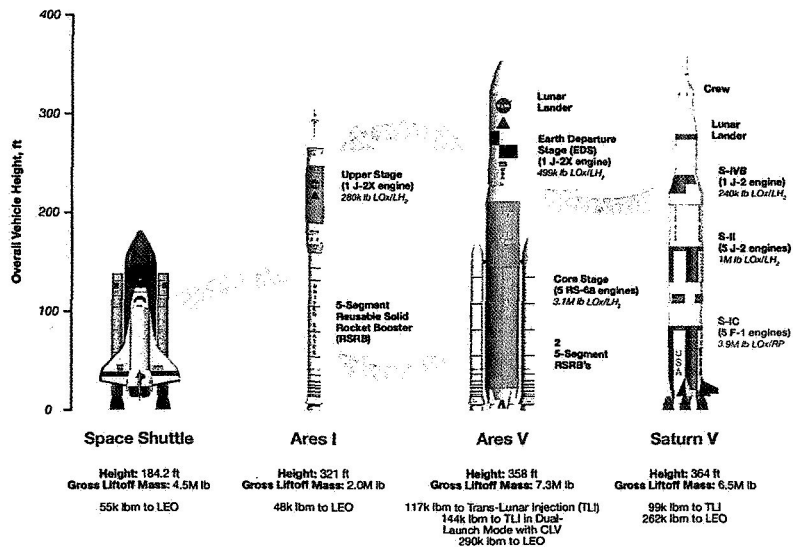


Figure 3. Launch vehicles comparisons (blue arrows indicate hardware commonality).

## II. Risk-Based Technical and Management Approach

The Exploration Launch Projects Office has been chartered by the Constellation Program, located at NASA's Johnson Space Center, and the Exploration Systems Mission Directorate, located at NASA Headquarters, to deliver safe, reliable crew and cargo launch vehicles designed to minimize life-cycle costs so that NASA can concentrate its resources, both budget and personnel, on missions of scientific discovery. To that end, the Space Shuttle follow-on systems are being designed and developed to maximize safety and reliability margins, with an eye on affordability of near-term development and long-range operations activities.

Project engineers and managers are working closely with the Space Shuttle Program to transition hardware, infrastructure, and workforce assets to the new launch systems, leveraging a wealth of knowledge gained from Shuttle operations over the last several decades. In addition, NASA and its industry partners have tapped into Saturn information databases and are applying corporate wisdom conveyed firsthand by Apollo-era veterans of America's original Moon missions in the late 1960s and early 1970s. Learning from its successes and failures, NASA employs rigorous systems engineering and systems management processes and principles in a disciplined, integrated fashion to further improve the possibility of mission success.

With a "test as you fly" philosophy, the Exploration Launch Projects Office draws on analysis from computer-aided modeling and simulation applications that test integrated avionics software and simulate vehicle dynamics in cyberspace. The Exploration Launch Project team also gains insight into three-dimensional configurations from subscale wind tunnel model testing. These preliminary analyses lead to real-world testing with increasingly flight-like hardware to gain confidence in the systems before orbital flight tests that will yield even more information on which to base critical hardware and operations decisions.

Using rigorous systems engineering standards and guidelines provides a framework for both internal and external independent reviews, with clearly defined entrance and success criteria on which to base decisions.<sup>5</sup> Major milestone reviews, shown in Table 1 below, help guide the design to a space transportation solution that fulfills customer and stakeholders requirements on time and within budget.

**Table 1. NASA project technical reviews.**

Review Title	Review Purpose/Outcome
<b>System Requirements Review (SRR)</b>	Assures that requirements are properly defined, verifiable, implemented, and traceable, and that the hardware and software are designed and built to the authorized baseline configuration.
<b>Preliminary Design Review (PDR)</b>	Provides completed design specifications, the identification and acquisition of long-lead items, manufacturing plans, and life cycle cost estimates; the design is 30% complete and element specifications are baselined.
<b>Critical Design Review (CDR)</b>	Discloses the complete system in full detail; ascertains that technical problems and design anomalies have been resolved; and ensures that the design maturity justifies the decision to begin fabricating/manufacturing, integration, and verification of mission hardware and software. The design is 90% complete.
<b>Design Certification Review (DCR)</b>	Serves as the control gate that ensures the system can accomplish its mission goals. Requirements are verified in a manner that supports launch operations.
<b>Flight Readiness Review (FRR)</b>	After the system has been configured for launch, the FRR process examines tests, demonstrations, analyses, and audits that determine the system's readiness for a safe and successful launch and for subsequent flight operations. The Project Manager and Chief Engineer certify that the system is ready for safe flight.

### III. The Ares V Design Concept and Mission Scenario

In keeping with its systems engineering and risk-based technical and management approach, the Ares V vehicle, currently in the early planning and design stages, has undergone a series of concept studies to determine the most appropriate vehicle design for the requirements levied by the missions ahead.

A side-by-side expanded view of the current Ares I and Ares V baseline configurations for lunar missions is shown for reference in Figure 4. The Ares V consists of two Shuttle-derived 5-segment Reusable Solid Rocket Boosters (RSRBs) using polybutadiene acrylonitrile (PBAN) propellant, similar to the Ares I first stage. The Ares V core stage is a 33-foot-diameter tank delivering liquid oxygen/liquid hydrogen (LOX/LH<sub>2</sub>) to a cluster of five RS-68 engines. The Ares V Earth Departure Stage (EDS), which carries payloads such as the Lunar Surface Access Module (LSAM), is similar to the Ares I upper stage. The J-2X engine (LOX/LH<sub>2</sub>) that powers the Earth Departure Stage is a derivative of the Saturn upper stage engines and is similar to the Ares I upper stage engine. This hardware commonality is expected to reduce both development and operations costs.

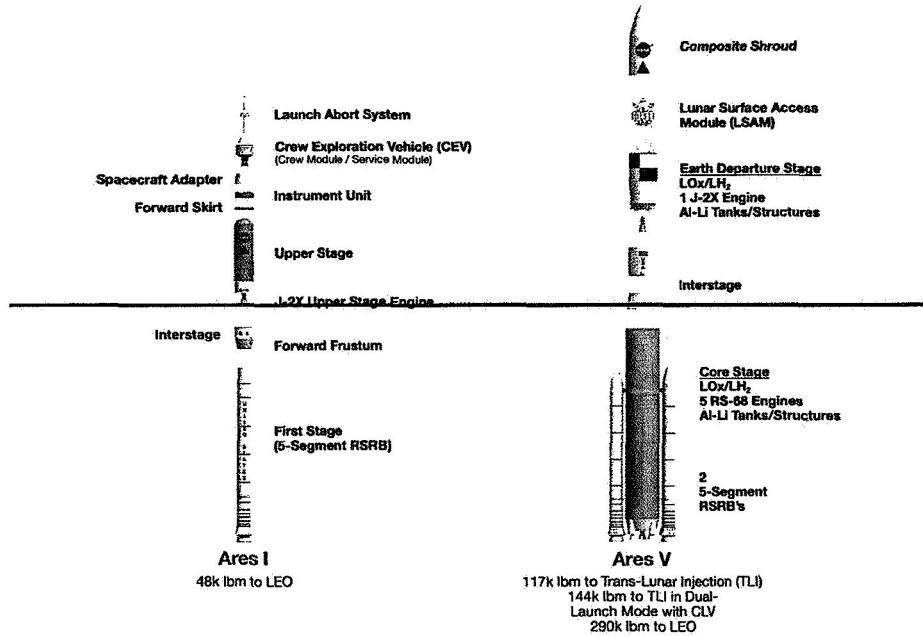
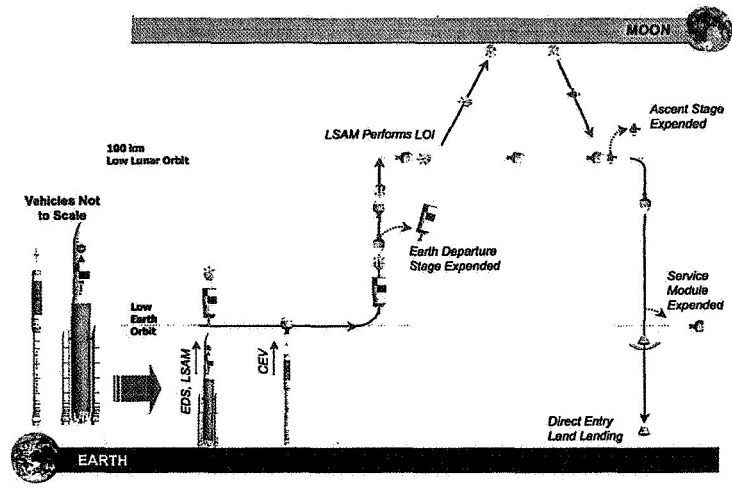
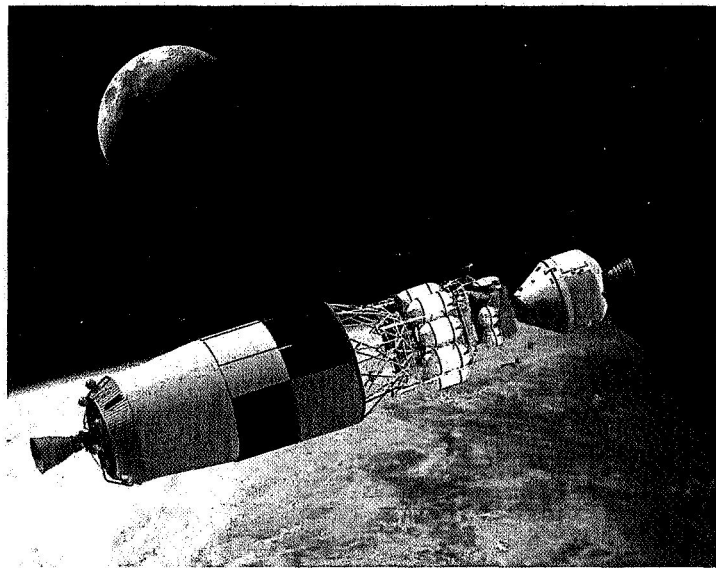


Figure 4. Expanded views of Ares I and Ares V show common hardware.

The lunar mission scenario is shown in Figure 5. During launch, the Reusable Solid Rocket Boosters and core propulsion stage power the Ares V to position the Earth Departure Stage for a suborbital burn. After separation from the spent core stage, the J-2X engine will place the vehicle into a circular orbit. The Crew Exploration Vehicle, delivered to orbit by the Ares I, will dock with the Earth Departure Stage carrying the lunar lander (see Figure 6). The J-2X engine will fire to achieve escape velocity; the Earth Departure Stage will be jettisoned when the mated crew and lunar modules are on course for the Moon. Once the astronauts arrive in lunar orbit, they will check out systems, transfer to the lunar lander, and descend to the Moon (Figure 8), while the crew module remains in orbit. After their objectives have been met, the astronauts will return in the lunar lander and rendezvous with the crew module to return to Earth.



**Figure 5. Lunar mission scenario.**



**Figure 6. Crew Launch Vehicle docked with the Lunar Surface Access Module (artist's concept).**

### **A. Exploration Systems Architecture Study Proposes Initial Recommendations**

To provide a frame of reference for the current Ares V baseline configuration, it is useful to review the genesis and evolution of the concept over the past year. The Exploration Systems Architecture Study (ESAS) team was chartered in spring 2005 to develop and assess viable launch system configurations for a Crew Launch Vehicle and a Cargo Launch Vehicle to support lunar and Mars exploration and provide astronaut access to the International Space Station.

The Exploration Systems Architecture Study team, which was comprised of Government aerospace experts, developed potential launch vehicle design concepts; assessed dozens of candidate concepts against figures of merit (safety, cost, reliability, and extensibility); identified and assessed vehicle

subsystems and their allocated requirements; and developed viable development plans and supporting schedules to minimize the gap between Shuttle retirement and the Crew Exploration Vehicle's initial operational capability, preferably in the 2011 timeframe. The study team explored concepts derived from elements of the existing Evolved Expendable Launch Vehicle (EELV) fleet and the Space Shuttle.

In fall 2005, the Exploration Systems Architecture Study team released a report that recommended a heavy-lift launch vehicle configuration.<sup>6</sup> This point-of-departure vehicle was based on two 5-segment Reusable Solid Rocket Boosters and five Space Shuttle Main Engines (SSMEs) modified to be expendable rather than reusable, a 27.5-foot-diameter core tank derived from the Shuttle's External Tank, and the J-2S+ upper stage engine.

### B. Bottom-up Review Refines Concept

As a part of its standard design process, NASA applies systems engineering methodologies to validate customer and stakeholder requirements in relation to vehicle concept designs. Through systems engineering, trade study analyses are conducted to determine the optimum solutions that meet and exceed requirements, focusing on factors such as safety, reliability, maintainability, supportability, and operability. Following the Exploration Systems Architecture Study, in spring 2006, the Constellation Program tasked the Exploration Launch Office with performing follow-on studies in the areas of technical scope in relation to budget guidelines and schedule targets.

As a result of this comprehensive bottom-up review, the Constellation Program adopted a revised vehicle configuration (see Figure 7) based on analyses performed by rocket engineers and business professionals, which gave clear evidence that the RS-68 engine could offer significant savings over redesigning the reusable Space Shuttle Main Engine — a complex, reusable, human-rated engine — for this expendable application. Developed by Boeing (Pratt & Whitney Rocketdyne) for the U.S. Air Force's Evolved Expendable Launch Vehicle Program, the RS-68 now powers the Delta IV launch vehicle family. Building on lessons learned from the Space Shuttle Main Engine Project, the development time for the relatively new RS-68 was cut in half and the parts count was reduced by 80 percent. Touch labor for the RS-68 was reduced by 92 percent over the labor-intensive Space Shuttle Main Engine processing, and non-recurring costs were cut by 20 percent.<sup>7</sup>

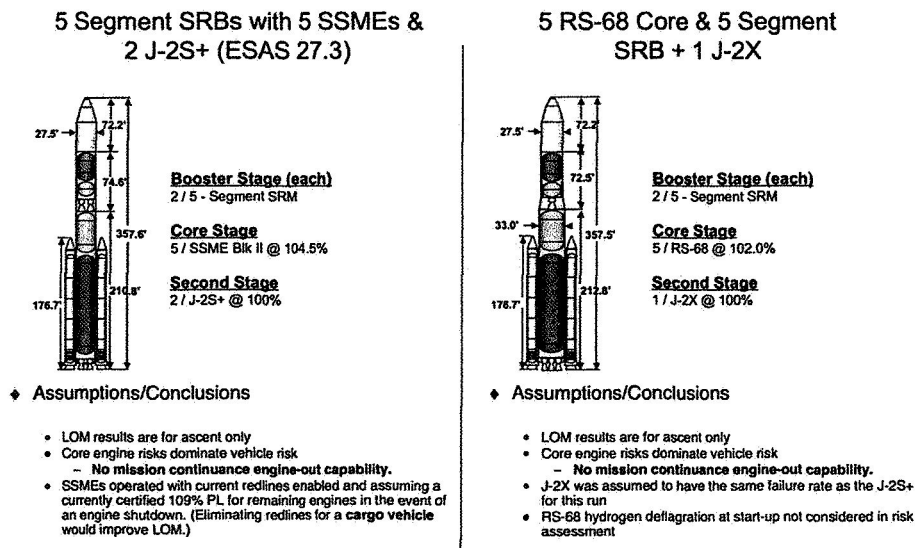
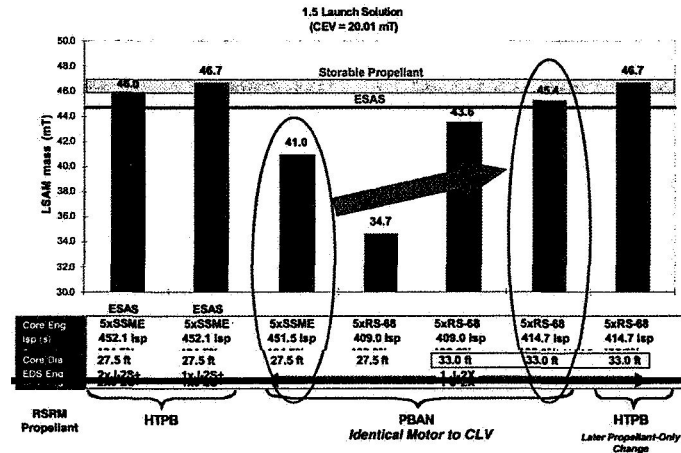


Figure 7. Comparison of ESAS proposal on left and revised baseline on right.



Adopting this plan offers multiple benefits by developing one Reusable Solid Rocket Booster and one upper stage engine, reducing the total number of separate major hardware elements originally proposed. It also capitalizes on a low-cost expendable engine that can meet the high production rates that will be needed for Ares V lunar missions. The resulting funding profile is more sustainable across the years ahead, as this plan is expected to reduce both recurring and nonrecurring operations costs through infrastructure and logistics (manufacturing, testing, shipping, and processing) considerations. In addition, as is shown in Figure 8, the baseline configuration adopted following the bottom-up review exceeds Constellation Program payload requirements.



**Figure 8. Performance gains are realized through the Ares V configuration evolution.**

This hardware solution evolution is an example of how NASA is reducing technical and business risk. In fact, the Ares V team is collaborating with the U.S. Air Force for RS-68 engine upgrades currently in progress, which will reduce Constellation Program cost and schedule risks. Subsequent flights of upgraded RS-68 engines on the Delta IV will yield valuable performance data that can be directly applied to the Ares V version, reducing technical risk. The RS-68 engine is the most powerful liquid oxygen/liquid hydrogen engine now in existence. When modified to meet NASA's standards (see Figure 9), the five-engine cluster/33-foot-diameter tank will exceed the Constellation Program's payload lift requirements. Studies are being conducted to determine the potential of rating the RS-68 for human flight in the future. More information is included in the Commonality Assessment section below.

Another outcome of the Constellation Program's new Ares V baseline configuration is the Saturn-class 33-foot-diameter core stage, which delivers the propellant needed for lunar missions and provides exhaust clearances for the RS-68 nozzle. The Michoud Assembly Facility, located in Louisiana, manufactured the Saturn V structure and now produces the Shuttle's External Tank. The Ares V core stage tank and Earth Departure Stage structure, as well as the Ares I upper stage, also will be manufactured and processed at Michoud (see Figure 10).

For this study, loss of mission (LOM) estimate comparisons of the Space Shuttle Main Engine/27.5-foot-diameter core stage and the RS-68/33-foot-diameter core stage were based on probabilistic data generated using the Flight-oriented Integrated Reliability and Safety Tool (FIRST), which provides a rapid quantitative probabilistic risk assessment of launch vehicle and spacecraft designs. The methodology also included the Space Shuttle Main Engine reliability assessment from the Exploration Systems Architecture Study, taking into account that it has been flown on 115 missions and has over a million seconds of operation from which to extrapolate information. Such factors were qualitatively weighted in an effort to make more accurate assessments of a mature, well-understood human-rated engine designed for 55 flights, versus a fairly new engine designed for low-cost expendability, with only 6 flights, 269 starts, and 39,300 seconds of test time.



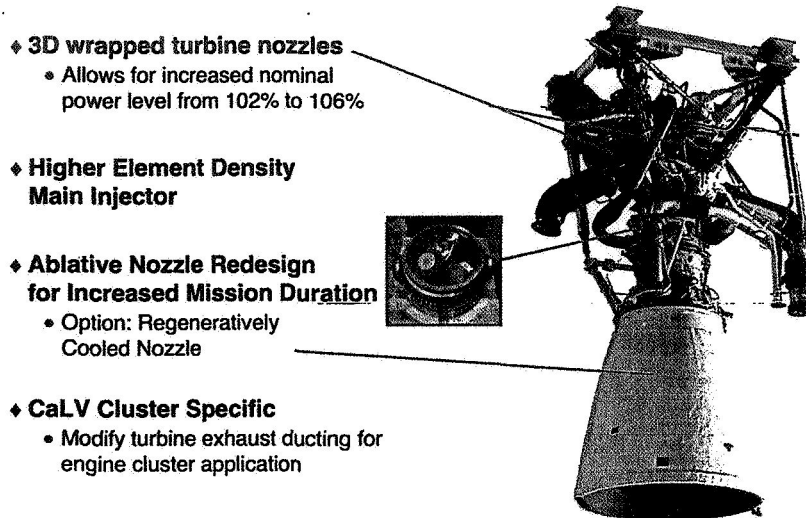


Figure 9. RS-68 engine, showing a selection of planned modifications.

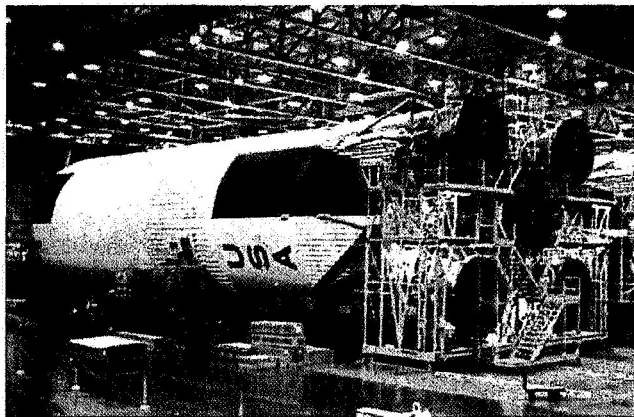


Figure 10. The 33-foot-diameter Saturn V was processed at the Michoud Assembly Facility.

While the upgraded RS-68 engine’s demonstrated reliability is less than that of the Space Shuttle Main Engine, by the time it has gone through testing and certification, its reliability will be more than adequate for the Ares V. The RS-68 engine’s capability for more direct modification preserves the path to human-rate the Ares V as part of a comprehensive production improvement process. Table 2 gives a top-level summary of the safety/reliability benefits of the recommended approach.

**Table 2. Safety and reliability summary.**

<p><b>RS-68 engine modifications are easier due to a simpler combustion cycle.</b></p>	<ul style="list-style-type: none"> <li>• RS-68 changes are not considered high-risk.</li> <li>• Space Shuttle Main Engine changes are more difficult.</li> <li>• Space Shuttle Main Engine changes increase risk significantly beyond known changes.</li> </ul>
<p><b>Greater potential to increase the safety of the RS-68 by bringing it up to Space Shuttle Main Engine safety level.</b></p>	<ul style="list-style-type: none"> <li>• Avionics modifications can be phased in to leverage advances in technology, increasing safety as the Ares V system matures.</li> <li>• The regeneratively cooled nozzle option provides a significant safety increase due to the ability to green-run the nozzle/engine combination and allows growth for in the burn duration for missions and abort scenarios.</li> </ul>

### C. Commonality Assessment

More recently, the Commonality Assessment, conducted in May 2006, brought together a multi-disciplined panel of aerospace experts, some with Saturn and Shuttle experience, to assess potential synergy points and design challenges between the Ares I and Ares V vehicles.<sup>8</sup> Driven by the upcoming Ares I System Requirements Review (SRR) and Ares V Initial Requirements Review (IRR), the panel was chartered to help determine which Ares V requirements might have the most impact on the desired commonality of hardware systems and components between it and the Ares I. Challenges and risks identified during the process led to follow-on analyses to support the Design Analysis Cycle leading to the Ares I System Requirements Review planned for fall 2006.

The Commonality Assessment Report results are being used to perform advanced concept studies using the Vehicle Integrated Performance Analysis (VIPA) modeling and simulation capability, along with other systems engineering tools and activities, to further validate the design configuration. An Ares V notional trajectory is provided for reference in Figure 11.

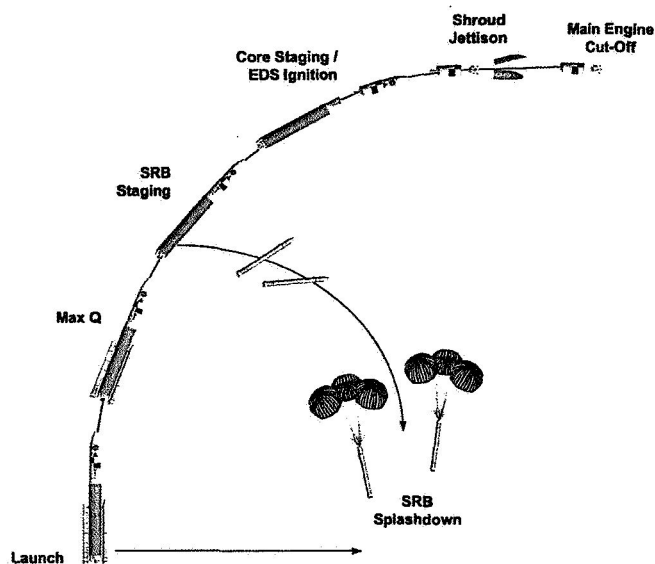


Figure 11. Ares V notional reference trajectory.

### *Mission Considerations*

The current Ares V mission concept stipulates three potential payloads for the Earth Departure Stage: the Lunar Surface Access Module for lunar missions, cargo to orbit, and a potential single-launch solution to the Moon in which the Crew Exploration Vehicle and lunar lander are both included as Ares V payloads. This mission definition drives several significant designs of the Earth Departure Stage. Each payload will require a different interface design, as well as have different payload servicing requirements, which may drive up design complexity and increase workloads for Ground Operations and Mission Operations. Also, extensive analysis will be required to derive and subsequently design for the induced environments on each of the three proposed payloads. Shroud separation systems will be specific for the payload, as well.

### ***Hardware Considerations***

Analysis of the Reusable Solid Rocket Boosters for the Ares V application, which will use significant common hardware from the Ares I first stage, centered on structural considerations, including differences in loads due to the Ares I single-stick configuration versus the Ares V multiple-body geometry. Different requirements for the forward and aft skirts may place some structural commonality at risk, but the reviewers concluded that significant potential commonality exists between the two vehicles. Input from the prime contractor, ATK Thiokol, also suggests that the Ares I will be the design driver when accounting for natural and induced environments on the boosters, particularly during reentry. This suggests that the Ares I, rather than the Ares V, configuration will be the significant structural requirements driver.

The booster payload capability currently is optimized for use as the Ares I first stage. To optimize for use by the Ares V, more thrust could be generated via a change in throat diameter, as well as a nozzle contour redesign. The Reusable Solid Rocket Motors also could be designed for a flatter trace via modified propellant grain design.

The two vehicles also have significant differences in tail-off requirements at separation of the first stage/boosters. The requirement for a steeper tail-off during Ares I operations to meet separation needs will introduce increased thrust imbalance during Ares V use. Also, the heavy-lift vehicle will require differential thrust between boosters for vehicle control and structural design, which may create a risk to commonality. Further study will evaluate the impact of the increased thrust imbalance on vehicle controllability, loads, and separation dynamics.

Both the Ares I first stage and the Ares V boosters will use existing heritage systems from the Shuttle Program, including documentation; planning, inspection, and verification procedures; design tools; and methodologies. Full-scale test facilities also will be common between both vehicles. The manufacturing processes, tooling, facilities, resources, and supply chain will be common for the vehicles, both drawing on the legacy of the Shuttle Program. Ground support equipment (transportation, handling, and storage) developed for the Ares I first stage will be extensible to the Ares V boosters. In terms of hardware, the two vehicles can use common cases, joints, and seals, as well as igniters and insulation. The Thrust Vector Control interface will, likewise, be common between the two.

The Thermal Protection System for the entire vehicle will be different due to the different thermal environments experienced by the two vehicles. Plume effects will be a significant driver for the Ares V. Thrust Vector Control turbine exhaust also will need to be directed away from other bodies on the Ares V, while the Ares I single-stick configuration will not be similarly affected.

Commonality exists between both vehicles' parachutes and recovery systems, though the recovery system bounding loads may be significantly different for each launch vehicle. The flight profile differences will affect design, sequencing, and deployment of chutes. Both configurations can share common motor casings and kick-ring hardware. The Ares V also has commonality with the existing Shuttle booster hardware, including booster separation motors on the forward and aft skirts, presuming that loads and environments are similar.

The natural and induced environments in the two vehicles' launch scenarios vary greatly. The Ares I single-stick first stage ascent burn will result in significant differences in acoustic environments and thermal environments (particularly base heating on lift-off and during ascent) from the Ares V, with its dual solid boosters and five RS-68 engines all firing at the same time. Prior to lift-off, the propellant mean bulk temperature (PMBT) differences in the two vehicles also may affect commonality. The Ares I's symmetrical single-stick configuration presents a much different on-pad propellant management scenario than the Ares V, which has two boosters in proximity to the cryogenic core stage. The configurations of the two vehicles also will require different mounting of booster separation motors, as well as functional differences due to desired booster behavior at separation between the two vehicles.

The Ares V aft skirt will support higher loads and require additional TPS to cope with the thermal environment induced by the five RS-68 engines. The forward structure serves as the primary load path on the Ares I, whereas the Ares V boosters will be subjected to attach loading similar to the current Shuttle configuration. Design changes for the Ares V include a frustum/nose cap similar to those used on the current Shuttle boosters.

Structures also will differ to account for the aerodynamic and thermal environment of the Ares V boosters during RS-68 fly-by post-separation. Reentry aerodynamic environments also will be significantly different, though it has been posited by the prime contractor (ATK Thiokol) that the Ares I reentry will be a more significant driver in this regard. Aeroshell jettison for reentry events is another issue that will be analyzed to determine risks to commonality.

The core stage also could pursue commonality with the Ares I Upper Stage/Ares V Earth Departure Stage. Common components could be utilized for avionics (harness and connector types), instrumentation, Main Propulsion System ancillary components, and materials for tanks and structures. Common manufacturing processes are possible here, as well, including friction stir welding of tanks.

Launch pad modifications also will be necessary for the Ares V to address the potential debris risks at liftoff to the RS-68 nozzles, as well as hold-down capabilities due to RS-68 start up. Sequential or paired engine start will introduce moments that will be carried by the Reusable Solid Rocket Boosters.

### ***RS-68 Engine Recommendations***

The Commonality Assessment panel also discussed modifying the RS-68 for use in the Ares V core stage, both for performance gains and for safety improvements. A number of changes are necessary to mitigate or eliminate known issues — chiefly, reduction of free hydrogen at engine start and the engine's current excessive helium requirements for operations. Following are examples of RS-68 engine changes:

- The current RS-68 blisk uses an asymmetric turbine nozzle design, which creates high loading on the blades. In order to attain the 106% power level, a 3D first stage nozzle will be incorporated on both the oxidizer and fuel turbopump turbines to reduce the risk of blade cracking.
- Increased element density in the main injector will allow for improved propellant mixing and increased combustion efficiency. Testing has been performed with both 28-element and 40-element injectors to ascertain the most advantageous injector density. (See Progress and Plans section below.)
- A material change in the engine bearings is recommended from the current 440C to Cronidur 30 in order to address a known issue with stress corrosion cracking on the bearings.
- The current RS-68 turbine exhaust ducts extend out from the engine to a sufficient degree to impact the planned five-engine configuration. Trade studies should be conducted regarding the manifolding of these exhaust ducts, exploring various design concepts to determine the best solution. There is a potential performance risk associated with manifolding the exhaust ducts, as it can create turbine pressure ratio problems.
- The current ablative nozzle of the RS-68 must be modified for Ares V use. A thicker nozzle wall will be required due to the increased burn time of the Ares V over that of the Delta IV. Optimization of the inner nozzle contour may also be desirable from a performance standpoint. However, the thicker nozzle wall may cause a significant weight increase per engine (approximately 500 pounds).

A move to using a regenerative cooled nozzle in place of the current ablative nozzle has been proposed to provide an increase in specific impulse by warming fuel, as well as to realize significant weight savings, particularly in light of the risk of weight increase with a thickened ablative nozzle wall. The new regenerative nozzle would need to have minimal impact to the current engine design.

It may be possible for both the RS-68 and J-2X engines to utilize common components and software for the engine controller, as well as instrumentation, pyrotechnic igniters, and ancillary components such as check valves, solenoid valves, and so forth. In addition to subsystem components, the two engines could pursue common manufacturing processes (e.g., HIP bonded main combustion chamber).

These and many other Commonality Assessment insights provided a framework for current and future trade studies as the Ares I and Ares V designs are refined to the template of mission requirements, including those levied by the Constellation Program Level on the integrated vehicles which, in turn, drive the various elements and components.

#### IV. Progress and Plans

Although it will be a number of years before the Ares V begins flying missions to the Moon, the initial planning effort has received “seed money” to begin the lengthy process of designing, developing, and fielding a new heavy-lift launch vehicle system. A notional schedule is provided in Figure 13. Using the resources at hand, the Ares V team made measurable progress in the 2005 to 2006 timeframe and is planning to ramp up the workload in 2007. This section summarizes recent accomplishments and provides a look ahead at tasks to be started in the near future.

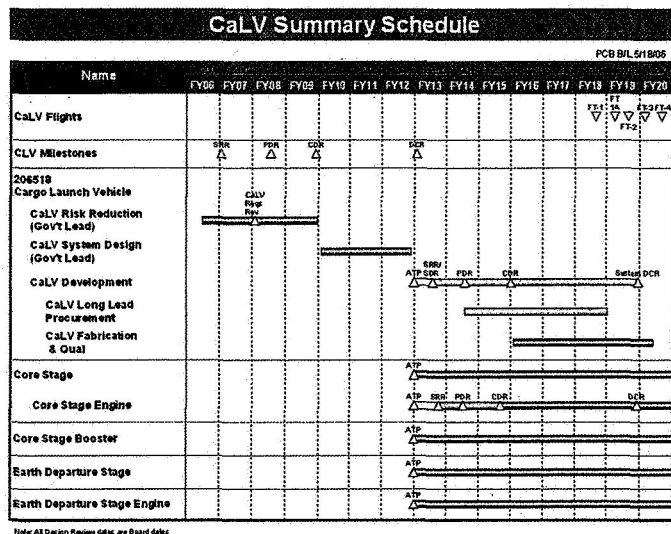


Figure 13. Notional Ares V schedule.

#### A. Accomplishments

Since the Ares V launch vehicle shares common hardware with the Ares I, as discussed above, it benefits from work currently being performed on those elements as part of the Ares I design, development, testing, and evaluation process. Given below is an example from the first stage, upper stage, and upper stage engine efforts that give insight into future Ares V challenges and opportunities.

#### Static Test Firing

As the Shuttle Program made preparations to fly a mission in summer 2006 (STS-121), a 2-minute test of the Reusable Solid Rocket Booster was performed at the ATK Launch Systems test facility. The flight support motor burned the same amount of time as that for an actual Shuttle launch. The test article had over 117 instrumentation channels to capture data for dozens of objectives. Analysis results have a dual benefit for the Shuttle Program and the Ares I first stage element. As reported in Aviation Week and Space Technology, the extensibility from the Shuttle Reusable Solid Rocket Booster to the Ares V first stage “eliminates the need to start from square one. At the same time, it draws on workforce experience built up over the past quarter century.”<sup>9</sup>

### ***Upper Stage Request for Information***

A series of well-planned acquisitions has kept work on the new upper stage moving at a brisk pace. To illustrate, in spring 2006, a request for information was issued to the aerospace community for strategic input on manufacturing the Ares I upper stage, which is an in-house NASA design that also will inform and influence the Ares V Earth Departure Stage design. Responses received addressed both technical and business challenges. In particular, approaches were sought to combining avionics or on-board electrical flight controls and guidance systems into the overall upper stage procurement. NASA also received feedback related to design and specification sharing among participants, commonality of design tools and software, methods of reducing component life-cycle costs, and seamless transition of contractual arrangements.

Following receipt of this information from interested parties, NASA conducted a well-attended open house at the Government-owned/contractor-operated Michoud Assembly Facility — a one-of-a-kind facility where, currently, the Shuttle External Tank is manufactured and shipped to the Kennedy Space Center (KSC). As discussed above, the Ares I upper stage and the Ares V Earth Departure Stage will be manufactured and assembled at Michoud, along with the core stage tank.

### ***Upper Stage Engine Injector Performance Testing***

Several candidate J-2X injector designs were tested in spring 2006, as a risk reduction strategy to increase confidence that the design can produce the specific impulse needed for both the Ares I and Ares V applications. The testing reflected the engine's operating conditions anticipated for the inaugural flights of both vehicles and yielded data that are helping engineers determine the simplest design to meet performance requirements.

Several subscale candidate designs were investigated and anchored to current and historical engines to promote a highly reliable and affordable J-2X engine design to propel the Ares I and Ares V. This test series, conducted at the Marshall Space Flight Center, verified how the C-star efficiency changes as a function of element density for the proposed injector designs. It also validated the system level power balance, for which C-star is the single most important variable. Although the Ares I is due to be fielded first, this is an example of how common hardware, such as the J-2X engine, also is helping the Ares V effort makes progress.

In addition to benefiting from the knowledge and experience being gained in these three major areas, the Ares V team performed comprehensive programmatic and technical planning, including developing a preliminary integrated master schedule and projecting resources — personnel, facilities, and budget. It also kicked off a number of in-house tasks and business development activities related to the RS-68 engine and the 33-foot-diameter core stage tank.

The Ares V team is formulating core stage propulsion technical, cost, and schedule in order to identify risks and develop mitigation plans to maximize resource allocations and assignments. The risk management process flow was developed and established through an engineering control board to ensure integration and accountability.

In keeping with NASA's systems engineering design process and risk-based-management approach to mission success, the Ares V team drafted its concept of operations document as a foundational piece of information upon which trade studies aimed at defining and refining mission scenarios will build. The team visited the Michoud Assembly Facility and the Stennis Space Center test stands to gain a firsthand understanding of capabilities and constraints, such as transitioning from Space Shuttle Main Engine testing to J-2X upper stage engine testing, followed by RS-68 core stage engine testing, which will overlap with the earlier J-2X engine development, qualification, and certification.

Perhaps the most important task of the past year has been to better define and solidify Ares V customer and stakeholder requirements, so that design and analysis work targets the most critical areas, such as mass and performance. As part of the requirements validation process, the Ares V team participated in various reviews and study forums, and contributed to overarching products such as the Exploration Launch Projects Plan and the Commonality Assessment Report — one aimed at

management integration, and the other at technical compatibility between systems. Ares V inputs were made to the System Integration Group, and an internal review was conducted to validate core propulsion stage requirements. Safety, reliability, performance, cost, and schedule technical performance metrics are in development.

To facilitate RS-68 engine upgrading activities, the Ares V team finalized a technical directive with Pratt & Whitney Rocketdyne and established an Upgrades Requirement Review schedule. NASA and the engine contractor met to determine the best options for helium-use mitigation and to plan for analysis and testing. As an integral part of this engine effort, the Ares V team established a formal working relationship with the U.S. Air Force to partner with them on the RS-68 engine work, which already is in progress.

## **B. Future Work**

Near-term activities support the long-range plan to further mature the Ares V requirements and resulting design, based on judicious trade studies and business planning. The current level of effort will be expanded to include more of the resources (personnel and facilities) deemed necessary for the magnitude of the work ahead.

Data obtained from a series of advanced concept studies in progress at the time this paper was prepared will help refine the Ares V mission scenario for maximum performance and reliability. The results of a materials processes study will help determine whether the vertical or horizontal welding approach is best for the 33-foot-diameter core stage tank. Technical interchange meetings will be conducted with the U.S. Air Force and the contractors Boeing (owner/operator of the Delta family of Expendable Launch Vehicles) and Pratt & Whitney Rocketdyne to further solidify the plans for upgrading the RS-68 engine.

Systems engineering and integration product development will include a core stage systems engineering management plan, which provides the framework for unifying the various working groups, product teams, and configuration management boards within the overall purview of NASA's technical excellence and governance models.<sup>10</sup> The Ares V Interface Requirements Document also will be developed to ensure that various linkage points (for example, power, command and control, communications, and mechanical interfaces) are clearly and completely defined. The production of such detailed documents is a prime risk reduction strategy to facilitate integration on the front end, before hardware is built, shipped, tested, and processed for flight.

## **V. Conclusion**

The Ares V Cargo Launch Vehicle will deliver large-scale hardware and provisions to space for establishing a permanent Moon base and extending a human presence beyond the International Space Station and low-Earth orbit. Working in tandem with the Ares I/Crew Exploration Vehicle combination, this heavy-lift vessel will provide a replacement for the venerable Space Shuttle. While NASA looks to the past for wisdom, it applies modern systems engineering and management practices and processes to ensure technical performance is delivered on time and within budget. Building on a foundation of legacy knowledge and heritage hardware increases the prospect of mission success in the complex business of space transportation.

NASA is accountable for delivering on the strategic goals set forth in the U.S. Vision for Space Exploration. Paving the way for the first human footprint on Mars begins with safe, reliable, and affordable launch vehicles capable of returning astronauts to the Moon, where they will prepare for longer missions to more distant destinations. The Ares V heavy-lift vehicle is an essential step along a path that will positively affect many generations to come, as NASA and its international partners chart a course to master space in the 21<sup>st</sup> century.



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