National Aeronautics and
Space Administration

Document Number
BASELINE (DRAFT)
RELEASE DATE: December 3, 2008

ARES V PRE-PHASE A STUDY REPORT

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1.0 Introduction

This document provides an overview of the Ares V Cargo Launch Vehicle (CaLV), including its mission and its role and interfaces within the Constellation (Cx) architecture, and discusses the development history of the Ares V, from the Exploration Systems Architecture Study (ESAS) in 2005 through selection of the Point-of-Departure (POD) Ares V concept approved at the Lunar Capabilities Concept Review (LCCR)/Ares V Mission Concept Review (MCR) in June 2008.

Note: The purpose of this document is to retain and document the decisions and analysis that have led to the current Ares V POD, as it has matured as a concept originating with ESAS through MCR in 2008. It is envisioned that this study report will evolve into several other documents, such as the Ares V Integrated Vehicle Design Definition Document (IVDD), the Ares V Systems Engineering Management Plan (SEMP), and other program-specific documents.

1.1 Overview

The Ares V CaLV provides the heavy lift capability for the Constellation Program's (CxP's) "1.5 Launch" architecture. A goal established during ESAS for Ares V, as well as the Ares I Crew Launch Vehicle (CLV), is to use proven technologies, components, and infrastructure from the Saturn, Space Shuttle, and contemporary Launch Vehicle (LV) programs. Also, where feasible, the Ares V Project is directed to seek commonality between the Ares LVs to minimize development and operational costs and improve safety and reliability. The vehicle components of the Cx architecture are shown in Figure 1.

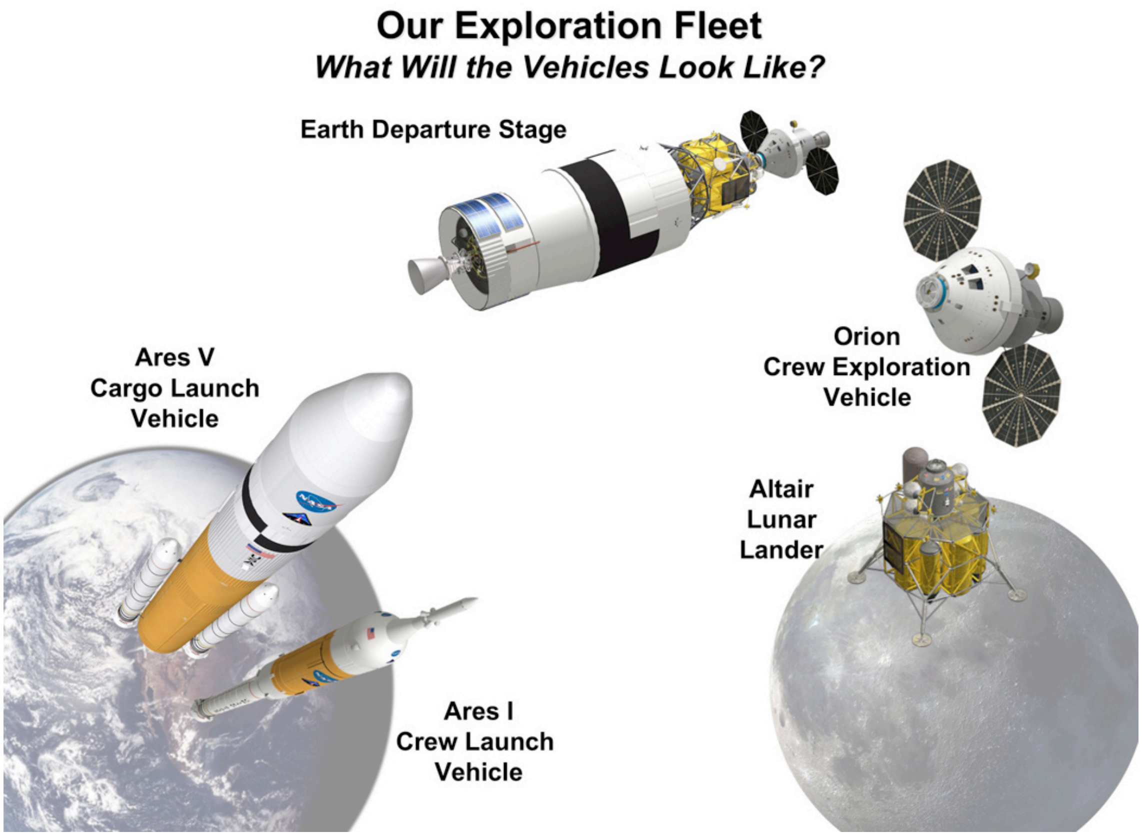

Figure 1 LVs and Spacecraft Components of the Constellation Architecture.

In order to carry out the National Space Policy directive to replace the Space Shuttle and complete the International Space Station (ISS), the Constellation development plan focuses on developing the Ares I and making it operational by 2015. Ares V is scheduled for a 2011 authority-to-proceed (ATP) decision that would enable it to make its first flight in 2018 and support lunar exploration in 2020. A notional Ares V schedule for planning purposes is shown in Figure 2.

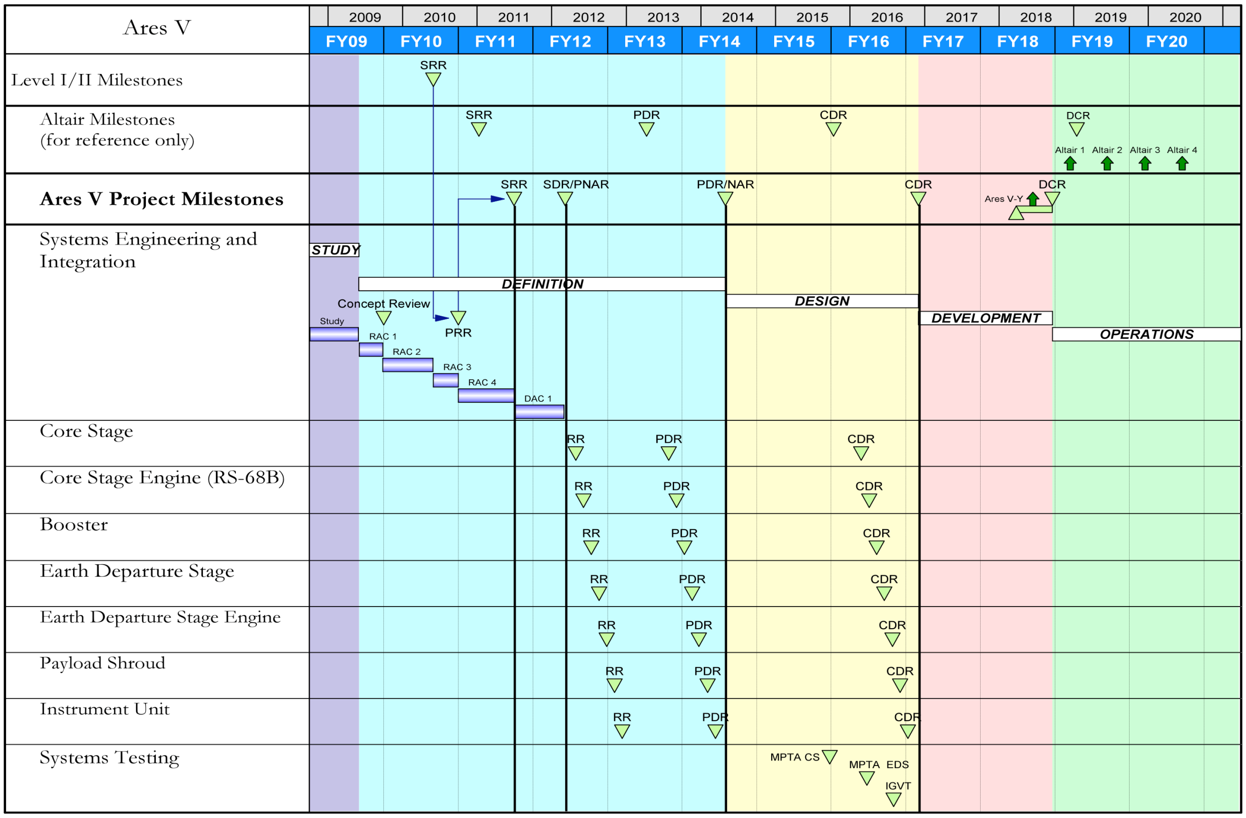

Figure 2 Ares V Notional Schedule for Planning Purposes

The primary mission of the Ares V is to launch the Altair lunar lander into Low Earth Orbit (LEO) and then send the lander and the Orion Crew Exploration Vehicle (CEV) into a Trans-Lunar Injection (TLI) trajectory to the Moon. (The Orion CEV is launched separately on Ares I.) In addition to crewed missions, Ares V will also launch automated cargo landers into LEO and on to specific lunar destinations. While retaining the goals of heritage hardware and commonality, the Ares V configuration continues to be refined through a series of internal trades to be discussed later in this chapter of the report. The most recent POD configuration was recommended by the Ares Projects and approved by the CxP during the LCCR/Ares V MCR in June 2008.

In the current mission profile (Figure 3), the Ares V is launched from Kennedy Space Center (KSC) in Florida. Following booster and core stage separation, the Ares V Earth Departure Stage (EDS) engine ignites at altitude, followed by separation of the payload shroud. Shroud separation occurs last in the staging sequence prior to reaching LEO to avoid re-contact with the LV stack. The EDS delivers the EDS-Altair stack into a stable LEO loiter orbit. Concurrently, the Orion CEV, launched by the Ares I, performs a rendezvous-and–dock maneuver with the Altair/EDS stack. After successful docking, ground controllers complete a system checkout of the EDS before it re-ignites its engine to perform the TLI burn and send the mated EDS-Altair-Orion stack to the Moon. The EDS is discarded after completion of the TLI burn, which marks the end of the Ares portion of the lunar mission. The current concept of operations calls for an Ares V launch as early as 90 min after Ares I, with three subsequent launch opportunities over the next 3 days, one launch opportunity per day. Ares V is currently designed for a 4-day loiter, with TLI on the fourth day.

Figure 3 Ares V Launch Profile for the Lunar Sortie Mission.

The design of Ares V shapes and is shaped by the requirements and designs of the other Cx components. The Ares V first stage booster is designed to share hardware, technologies, and manufacturing and operational facilities found in the Ares I First Stage. The Ares V EDS will also share the J-2X engine and various subsystems now being developed for the Ares I Upper Stage. The Ares V design also employs the commercial RS-68 engine now used on the Delta IV. In the case of all those common components (shown in Figure 4), the Ares V application will require modifications for the Ares V mission that requires ongoing interface with the relevant hardware and management organizations. Ares V must also interface with the Orion and Altair projects regarding basic weight and volume requirements, as well as numerous other design parameters, such as the payload adapter and utilities supplied to Altair, structural, thermal and acoustic loads, on-orbit power and thermal requirements, etc.

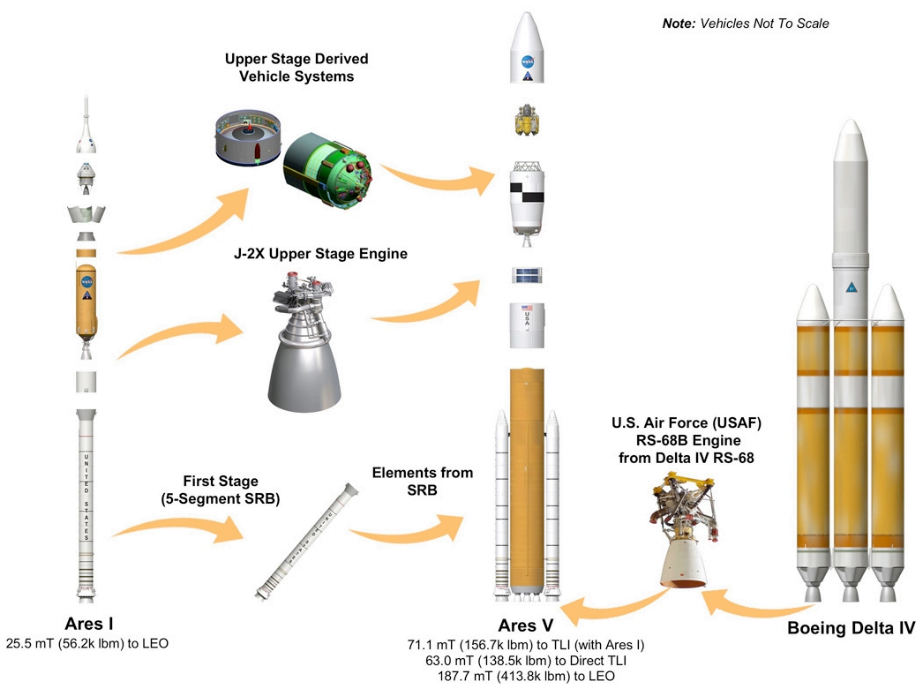

Figure 4 Heritage Systems Utilized on Ares V.

1.2 Ares V Top-Level Goals

The Constellation Architecture Requirements Document (CARD) provides the mass requirements for both the Lunar Sortie (crewed) and Lunar Cargo Design Reference Missions (DRMs).

For the sortie mission, the CARD specifies an Orion control mass of 20.2 t (44,500 lbm) and a Lunar Lander control mass of 45 t (99,208 lbm). The total TLI payload requirement is 66.9 t (147,575 lbm). The sortie mission assumes a LEO destination orbit of 242 km (130 nmi) at 29 degrees inclination. The CARD loiter duration is not specified but has continued to evolve with program and project trades from 95 days to 14 days. For the LCCR trades, it was further reduced to 4 days. The TLI maneuver begins at a minimum 185 km (100 nmi) altitude with a Delta Velocity (ΔV) requirement of 3,175 m/s (10,417 f/s) plus gravity loss.

For the cargo mission, the CARD specifies a Cargo Lander control mass of 53.6 t (118,168 lbm) and a total TLI payload mass of 54.6 t (120,372 lbm). The cargo mission assumes a phasing orbit Earth-To-Orbit (ETO) destination. Because Orion is not part of the cargo mission operations concept, a loiter requirement is unnecessary; however, a few revolutions in LEO is anticipated to allow for system checkout prior to the TLI burn. It is worth noting that the Saturn V TLI payload capability was 48.6 t (107,445 lbm) for the Apollo 17 mission.

The CARD also imposes additional requirements on the Ares V, such as the use of the five-segment solid rocket booster and five RS-68B engines in the Core Stage and the Mars mission mass requirements.

1.3 Ares V Evolution From ESAS to LCCR/MCR

The first designs for a heavy lift capability that would come to be dubbed as Ares V were studied during the ESAS, which began in 2005. From ESAS to the concept approved during LCCR as the new Ares V POD concept, NASA has studied more than 1,700 configurations of the Ares V. This section will summarize the evolution of Ares V from the ESAS trades up to the 51.0.39 POD concept that served as the entry point to the LCCR trade study. An overview of the Ares V development history is shown in Figure 5 below, including the LCCR trade space options and recommended POD concept approved by CxP, both of which will be detailed in later sections. A description of the major trades leading to the pre-51.0.39 concept follows.

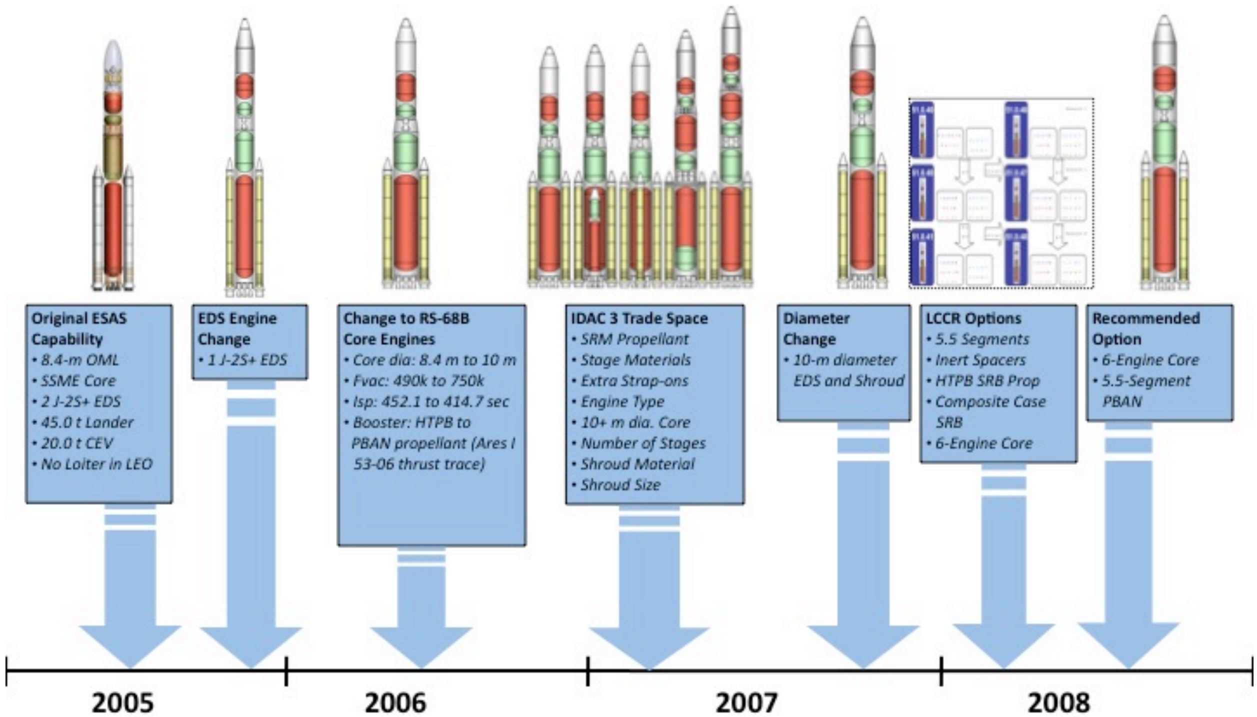

Figure 5 Ares V Concept Evolution from ESAS to LCCR.

NASA studied hundreds of commercial, government, and concept LV architecture systems prior to 2005, culminating in the release of the ESAS final report. In a trade tree pruning exercise, the ESAS team evaluated the following options:

1. Non-assisted vs. assisted takeoff
2. Vertical vs. horizontal takeoff
3. In-flight propellant tanking vs. no tanking
4. Rocket vs. rocket and air-breathing vs. air breathing propulsion
5. Expendable vs. partially reusable vs. fully reusable systems
6. Single-stage vs. two-stage vs. three-stage concepts
7. "Clean-sheet" vs. derivative systems.
8. Evolved Expendable Launch Vehicle- (EELV-) derived vehicles vs. both side-mount and in-line space Space Shuttle-derived vehicles vs. "clean-sheet" LV architectures.

Figures of Merit (FOMs) used in the studies were: cost, reliability, human safety, programmatic risk, mission performance, and schedule. These FOMs were applied to drive out the best option in the analysis. Additional considerations included legal requirements from the NASA Authorization Act of 2005, workforce skills, and industrial capabilities. After a thorough analysis of the entire exploration architecture requirements, EELV solutions were decided to be less safe, less reliable, and more costly than the Shuttle-derived solutions. The ESAS concluded that NASA should pursue a Shuttle-derived architecture for exploration due to several advantages relating to safety, reliability, and cost. The Shuttle-derived approach also allowed NASA to leverage significant existing ground infrastructure investments and personnel with significant human spaceflight experience. Overall, the Shuttle-derived approach was found to be the most affordable, safest, and reliable, both by leveraging proven human-rated vehicles and infrastructure elements and by using common elements across the architecture.

The ESAS-recommended Ares V vehicle, designated Concept 27.3, included two five-segment steel-case SRBs with Hydroxyl-Terminated PolyButadiene (HTPB) propellant, which has a higher specific impulse (Isp), density, and better mechanical properties than the Polybutadiene Acrylonitrile- (PBAN-) fueled Space Shuttle SRB. This Ares V concept had an 8.4-m (27.5-ft) diameter Space Shuttle External Tank-derived Core Stage powered by five RS-25 Space Shuttle Main Engines (SSME) redesigned to be low-cost and expendable. The 8.4-m (27.5-ft) diameter EDS was powered by two Liquid Oxygen (LOX)/Liquid Hydrogen (LH_2) J-2S+ engines. Based on the 1970s-era J-2S development program, the J-2S+ was intended to be a simplified version of the J-2 engine used for the Saturn upper stages. Both the Core Stage and EDS had Aluminum-Lithium (Al-Li) structures and propellant tanks. The Ares V variant had a Gross Liftoff Mass (GLOM) of nearly 2,900 t (6.4M lb). It was based on a 45-t (99,000 lbm) lunar lander, a 20-t (44,000 lbm) CEV, and no loiter capability in LEO.

In the subsequent NASA studies to refine the ESAS recommendations, the architecture was simplified to reduce the number of new development programs. Further analysis of EDS performance showed that the utilization of a single J-2S+ provided more performance than two J-2S+ engines, since the additional thrust provided by two engines during the ascent burn did not make up for the second engine's mass during the less-thrust-to-weight-sensitive TLI burn. When Ares I propulsion changed from a four-segment booster to a five-segment booster for the First Stage and from the RS-25 to a more powerful evolution of the J-2, dubbed J-2X, for the Upper Stage, it opened the trade space on Ares V. A single J-2X replaced the J-2S+ engine on the Ares V EDS. The RS-68B, a variant of the commercial engine flying on the Boeing Delta IV vehicle, was leveraged for the Ares V Core Stage. The RS-68 was designed as a simple, expendable engine with a high production rate. Using the RS-68 offered the opportunity to partner with the Department of Defense (DoD) to lower unit costs and gain flight maturity on Delta IV engine upgrades prior to Ares V flights. Program savings were estimated to be approximately $4.25 billion over the RS-25 SSME-based ESAS concept due to the high cost of producing a non-recovered, non-refurbished SSME.

Because of the RS-68B's lower efficiency, the core stage was enlarged from 8.4 m (27.5 ft) to 10 m (33.0 ft) in diameter to hold the additional propellants needed and to accommodate the larger nozzle and exhaust clearances needed for the larger engine cluster. The lower initial and recurring costs of the RS-68B, as well as the cost, technical, schedule, and reliability risks involved with redesigning the RS-25 for altitude start, outweighed the cost of developing Saturn-class tooling and facilities needed to manufacture and process the larger Core Stage. The booster design also reverted from HTPB to PBAN solid propellant for its better technical maturity. The resulting Ares V configuration, designated Concept 33.8.64, had a GLOM of 3,300 t (7.3M lbm) and was nearly 110 m (362 ft) tall. It exceeded the payload performance of the RS-25 solution by approximately 4 t (8,800 lbm) to TLI and enhanced the commonality between the Ares vehicles, improving both development and operational efficiencies.

Concept 33.8.64 evolved in a series of configuration trades involving shroud diameter, direct lunar missions, CEV and upper stage on the Ares V, added gravity losses on TLI burns, and Flight Performance Reserve (FPR) allocation change. The resulting POD was the 45.0.2 concept vehicle. Nearly 111 m (365 ft) tall, the new concept served as a benchmark to determine the effects of engine upgrades, SRB variations, alternate materials, added stages, added boosters, added engines and increased stage diameter. That effort established the impact of several changes that would be important to later trades, including composite tanks and structures, additional core stage engines, additional SRB's or Liquid Rocket Boosters (LRB's), and the addition of an S-II-class second stage.

However, the study also concluded that composite propellant tanks carried a high technical risk. HTPB boosters and a third stage carried undesirably high Design, Development, Test, and Evaluation (DDT&E) costs. Additional SRBs incurred undesirably high launch pad modification costs, and vehicles more than 122 m (400 ft) tall led to prohibitive KSC facility costs.

The 46- and 47-series were both studies of three-stage vehicles with four- and five- J-2X engine second stages, and shortened and lengthened Core Stages, respectively. Variants within those series traded the use of the commercial RL-10B2 engine on the third stage, six RS-68B core engines, nested tanks, and other changes. The three-stage designs offered higher performance and reduced loads through the TLI phase. They also allowed the Lunar Orbit Insertion (LOI) and TLI maneuvers to be performed by the third stage, which would reduce the size of Altair. However, the addition of a second stage with four to five J-2X engines (instead of one), and a unique third stage, added significant costs. The cost benefits to the Altair Project resulting from Ares V assuming the LOI functionality were shown to be minimal. Propulsion systems, particularly the number of engines, are primary contributors to Launch Vehicle reliability, and the increased number of engines for these three-stage options resulted in an overall lower vehicle reliability.

The 45-series then served as the starting point for trades that became the 51-series of Ares V concepts, which, in turn, served as the basis of the LCCR trade space formally assessed in June 2008. Figure 6 shows the common features and notable variants of the 45-, 46-, 47-, and 51-series concepts.

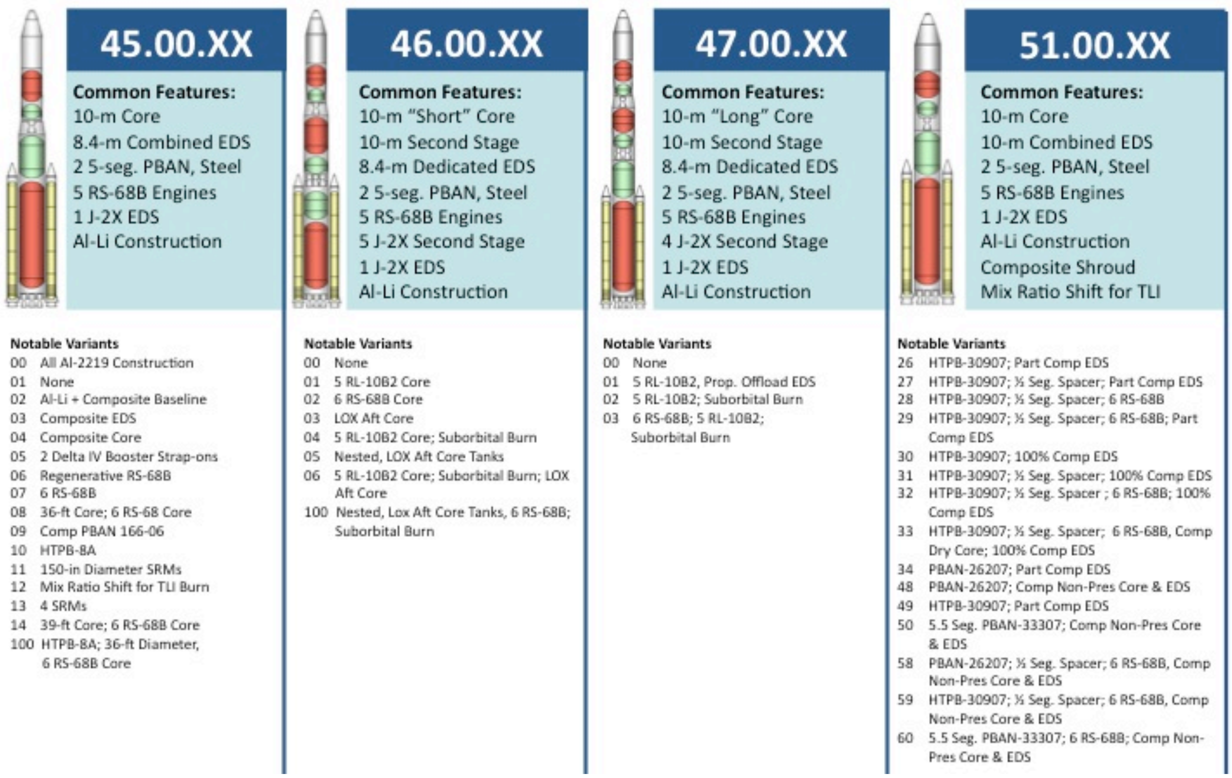

Figure 6 Recent Ares V Vehicle Concepts Leading to the 51-Series Concept.

Common features to all 51-series configurations are a 10-m (33-ft) diameter Outer Mold Line (OML); composite materials for the payload shroud and all dry structures; and metallic (Al-Li) propellant tanks for the EDS and Core Stage. The 51-series vehicles reflect the following changes in ground rules and assumptions to the 45.0.2 concept:

1. 4-day to 14-day loiter period
2. 222-km (120-nmi) to 242-km (130-nmi) injection orbit
3. 8.4-m (27.5-ft) to 10-m (33-ft) EDS diameter
4. 8.4-m (27.5-ft) to 10-m (33-ft) payload shroud

The 51-series trades were driven by the Performance Enhancement Study findings regarding increased Core Stage propellant load, SRB propellant and length, and the addition of a sixth Core Stage engine. The 51.0.39 concept was selected as the entry POD for LCCR and is characterized by its 10-m (33-ft) standard Core Stage with five RS-68B engines and two 5-segment steel-case PBAN-propellant reusable SRBs. Its TLI payload capability in conjunction with Ares I was 63.6 t (140,214 lbm). Details of the 51-series concepts for the LCCR trades will be described in the section addressing the vehicle trade space.

2.0 Figures of Merit

The Ares V team performed a range of analyses to assess concept vehicle sizing and performance, DDT&E and production costs, reliability (in particular Loss of Mission (LOM)), and sensitivity to key mission concepts. This section describes the overall analysis process used to weigh performance, cost, and reliability.

Performance, cost, and reliability analyses were performed for various concept vehicles. Major outliers for either cost or reliability were eliminated in an effort to narrow the trade space. The concept providing the optimal combination of performance, cost and reliability was then selected as the LCCR POD concept. Concurrent with the performance analyses, sensitivity analyses, particularly related to LEO loiter operations, were performed to assess sensitivity to vehicle performance and identify further trade studies and areas of improvement for the existing concepts.

The FOMs used to assess the vehicle options fell into the areas of performance, cost, and reliability. These Ares V FOMs follow the ESAS FOMs but have been updated to reflect current knowledge and guidance from CxP. While the cost and reliability FOMs are used to compare different vehicle concepts, the performance FOMs are defined as a pass/fail criteria.

2.1 Lunar Sortie TLI Payload Capability

The Lunar Sortie TLI Payload Capability is defined by the gross payload mass in metric tons (t) delivered to a TLI trajectory using the Lunar Sortie DRM ground rules. A performance floor of mission requirement plus a minimum of 5 t (11,000 lbm) with a goal of 9 t (19,800 lbm) was established for the mission. This definition corresponds to a minimum gross performance capability at TLI needed as 69.2 t. (152,600 lbm) to 74.2 t (163,600 lbm) from a departure orbit of 185.2 km circ at 29 degrees.

2.2 Lunar Cargo TLI Payload Capability

The Lunar Cargo TLI Payload Capability is defined by the gross payload mass in metric tons (t) delivered to a TLI trajectory using the Lunar Cargo DRM ground rules. A performance floor of mission requirement plus a minimum of 5 t (11,000 lbm) with a goal of 9 t (19,800 lbm) was established for the mission. This definition corresponds to a minimum gross performance capability at TLI needed as 58.6 t (129,200 lbm) to 63.6 t (140,200 lbm).

2.3 Vehicle DDT&E Cost

Costs associated with the DDT&E effort encompass the period from the beginning of Phase C/D at Authority to Proceed (ATP) through factory checkout of the first flight article. Costs associated with flight articles (test and operational) are excluded from DDT&E. Also, costs prior to the start of Phase C/D, and the costs of sustaining engineering and product improvements after first flight article checkout, are excluded.

DDT&E costs include the labor, material, Special Test Equipment (STE) and tooling, and other direct and allowable indirect expenses incurred by the prime contractor. These costs include all subcontracts to the prime required to determine compliance with all design requirements documentation and to perform the subsequent analysis, design, development, and redesign of test and development hardware. Also included are Project support costs, i.e., in-house labor, contractor support, travel, facilities, and Project Management (PM).

2.4 Vehicle Production Cost

Production cost is based on flight unit effort and includes the period beginning with the start of production initiated by long-lead procurements and ending with the delivery of the first unit. Flight unit costs incurred by the prime contractor and all subcontracts to the prime include the labor, materials, and other direct charges and allowable indirect charges required to produce the first flight article.

First flight unit costs are decomposed into fixed and variable cost components using a production rate curve methodology that reflects the fixed and variable natures of the cost to operate space launch systems. The fixed and variable costs are then applied against the LCCR flight manifest to obtain a time-phased production cost estimate. Also included are Project support costs to include in-house labor, contractor support, travel, facilities, and PM.

2.5 Loss of Mission

LOM is defined as loss of or inability to complete significant/primary mission objectives and is measured as the Probability of Loss of Mission (PLOM). For Ares V, the applicable PLOM is defined according to the following:

1. Ares V shall limit its contribution to the risk of LOM for lunar missions to no greater than 1 in 125.
2. Ares V EDS shall limit its contribution to the risk of LOM for lunar missions to no greater than 1 in 250.

2.6 Loss of Crew

Loss of Crew (LOC) is defined as death of or permanently debilitating injury to one or more crew members and is measured as the Probability of Loss of Crew (PLOC). The applicable PLOC for assessing Ares V is that Ares V EDS shall limit its contribution to the risk of LOC for lunar missions to no greater than 1 in 37,000.

3.0 Vehicle Descriptions

This section focuses on the trade space and the primary concept vehicles assessed during LCCR. The trade space is based on the 51.0.39 concept used as the entry point for LCCR and is briefly described here.

3.1 LCCR Trade Space

At the beginning of the CxAT Lunar Study, the Ares V LCCR trade space focused on six vehicles based on the 51-series configuration. This 51-series configuration established a set of features common to all vehicles within the trade space, specifically:

1. 10-m (33-ft) diameter OML for the central stack
2. Composite dry structures for Core Stage, EDS and shroud
3. Metallic propellant tanks for Core Stage and EDS
4. A single J-2X EDS engine
5. At least 5 Core Stage RS-68B engines
6. 9.7-m (31.8-ft) shroud barrel length

The trade space was created by combining variations of both the Core Stage and booster into different configurations of the Ares V vehicle. As one dimension of the trade space, two variations of the Core Stage were considered. The first variation consists of a standard size Core Stage with 5 RS-68B engines and the second variation represents an extended Core Stage with 6 RS-68B engines. As the second dimension of the trade space, three booster variations were leveraged to fully define the Ares V trade space. These booster variations were the 5-segment, PBAN, steel booster; the 5.5-segment, PBAN, steel booster; and the 5-segment, HTPB, composite booster. As was discussed in the Introduction, numerous vehicle permutations were analyzed leading up the 51.00.39 concept. The other 5 concepts that made up the LCCR trade space were the 51.00.40, 51.00.41, 51.00.46, 51.00.47 and 51.00.48. Figure 7 summarizes the common features to the 51-series trade space as well as the distinguishing elements of each trade space concept.

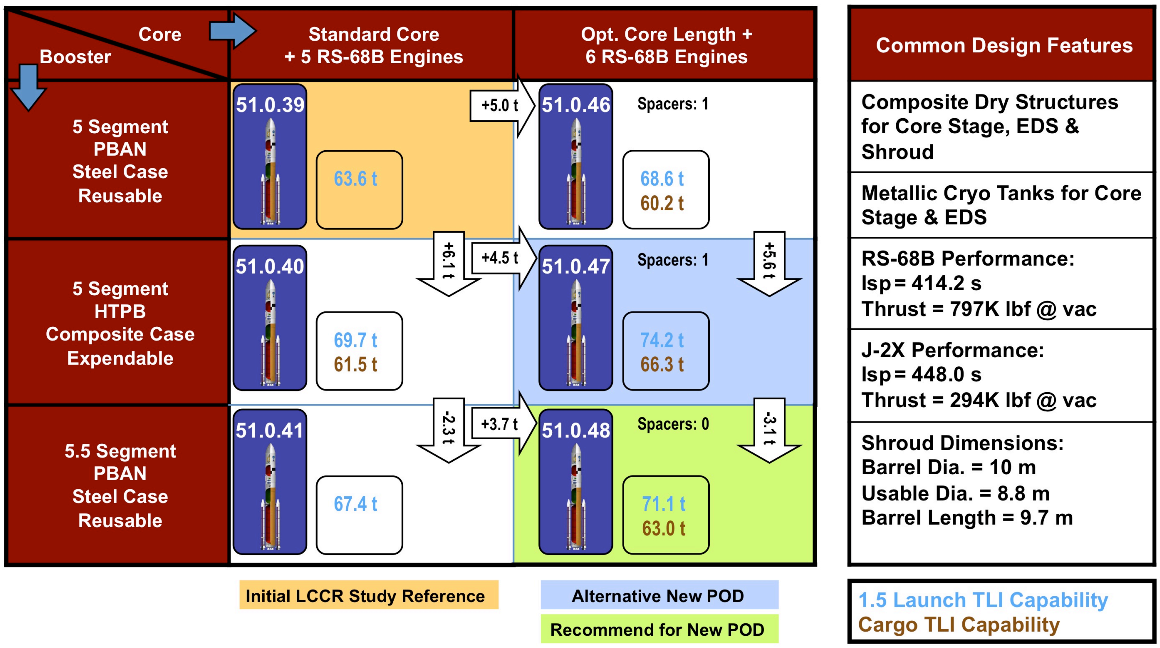

Figure 7 Ares V LCCR Trade Space (51-Series Vehicles).

The 51.00.39 concept vehicle is the entry POD to the CxAT Lunar Study. This vehicle features a standard Core Stage with 5 RS-68B engines and a 5-segment, PBAN, steel booster. It offers 63.6 t (140,200 lbm) of payload to TLI for crewed missions. The 51.00.39 does not meet the minimum performance requirement.

The 51.00.40 concept vehicle features a standard Core Stage with 5 RS-68B engines and a 5-segment, HTPB, composite booster. The 51.00.40 concept can deliver 69.7 t (153, 700 lbm) of payload to TLI for crewed missions. While this concept surpasses the minimum performance requirement, two other concepts within the trade space offer greater performance. The 51.00.40 was therefore eliminated from the trade space.

The 51.00.41 concept vehicle is a variant of the 51.00.39 concept. It has the same Core Stage configuration and features an additional half-segment, PBAN, steel booster. Given that the 51.00.41 provides 67.4 t (148,600 lbm) of TLI payload performance, it was removed from the final consideration.

The 51.00.46 concept vehicle features the optional, extended Core Stage with 6 RS-68B engines. It employs the standard 5-segment, PBAN, steel booster. The TLI payload capability is 68.6 t (151,200 lbm).

The 51.00.47 concept vehicle was chosen as an alternate concept during LCCR. Its design features the extended Core Stage with 6 RS-68B engines and the 5-segment, HTPB, composite booster. This particular combination of Core Stage and booster options offers the greatest TLI payload performance for crewed missions: 74.2 t (163,600 lbm). While this concept delivers the most payload to TLI, its design is dependent upon a successful infusion of composite technology development and incurs significant cost increases.

The 51.00.48 concept vehicle was chosen as the new POD concept at the LCCR. Its primary attributes are the extended Core Stage and the 5.5-segment, PBAN, steel booster. This POD vehicle support up to 71.1 t (156,700 lbm) of payload to TLI for crewed missions. This concept was maintained in the LCCR trade space because it provides a competitive level of TLI performance. Also, the 51.00.48 does not require significant funding for technology development nor does it incur the largest production and DDT&E costs.

3.2 Description of 51.00.48 POD Vehicle

During LCCR, the CxP selected 51.00.48 as the POD concept vehicle. The 51.00.48 vehicle meets the current CARD performance requirements plus some margin, but it does not fully meet the desired TLI payload goal of 75 t (165,300 lbm). This section describes the physical features and performance capability of the integrated vehicle and the individual elements.

3.2.1 Ares V POD Physical Description

The Ares V LV concept 51.00.48 is a two-and-a-half stage LV that delivers the Altair lunar lander and the EDS to LEO for rendezvous with the Orion crew vehicle system. The major components comprising the 51.00.48 concept are the 5.5-segment, PBAN-propellant SRBs, the LOX/LH_2 Core Stage, the LOX/LH_2 EDS, and the payload shroud. Figure 8 highlights the elements and their major features.

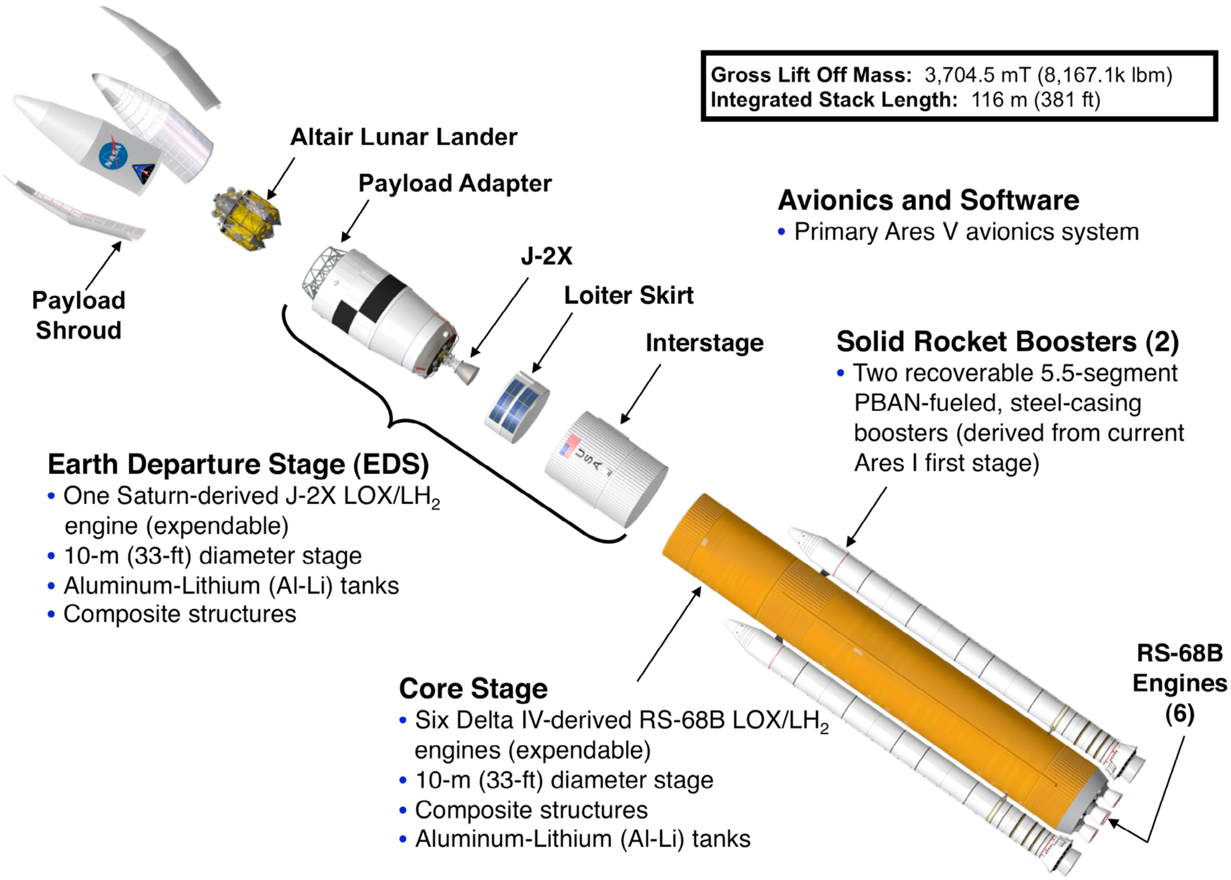

Figure 8 Expanded View of LCCR POD Concept: 51.00.48.

3.2.1.1 Ares V POD Core Stage Booster

3.2.1.1.1 Ares V POD Steel Booster Description

The "POD" booster configuration for the Ares V vehicle is designated as the 5.5-segment steel case configuration (Figure 9). The OML of the 5.5-segment steel case configuration is similar to the Shuttle SRB, but with five normal-sized STS/Ares I booster segments and a "one-half" booster segment. The propellant is the heritage STS/Ares I PBAN propellant. The design increases total booster propellant weight and permits a longer Core Stage with additional Core Stage propellant.

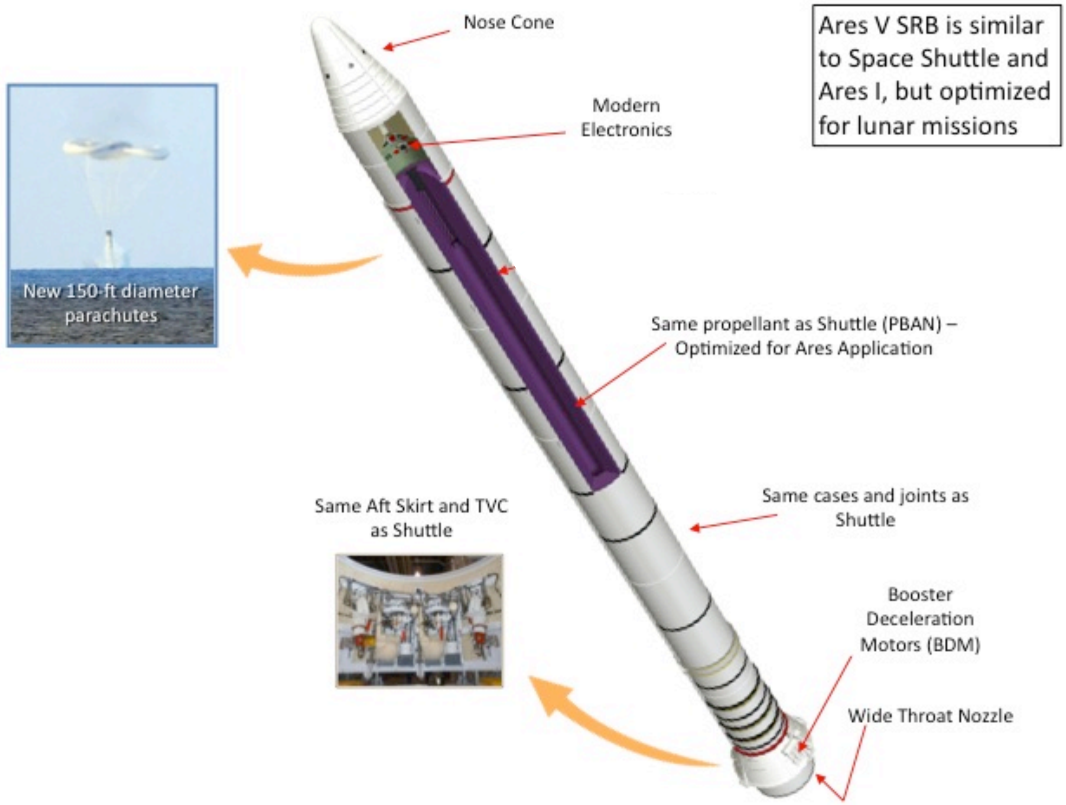

Figure 9 Ares V POD Booster: 5.5-Segment, PBAN Propellant, Steel Case.

The Ares V booster configuration uses heritage steel case cylinders and domes. The aft skirt, forward skirt, frustum, and nose cone are Shuttle SRB heritage configurations. The Core Stage-to-booster attach cylinder of the aft segment and the attach ring/struts are Shuttle SRB heritage. The "half segment" consists of a single Shuttle RSRM heritage case cylinder with a field joint on both ends. The case design Maximum Expected Operating Pressure (MEOP) is the same as the Shuttle SRB and Ares I booster design. The Thrust Vector Control (TVC) system is Shuttle SRB heritage. Boosters would be separated similar to Shuttle with STS/Ares I forward and aft Booster Separation Motors (BSMs).

The Ares V booster is planned for recovery to refurbish components similar to the Shuttle SRB. The parachutes and all equipment required for re-entry, splashdown, and recovery are included in the configuration.

3.2.1.1.2 Steel Booster Evolution

The initial 5-segment steel case booster configuration for the Ares V vehicle used the identical motor design (5-Segment RSRMV) as defined for the Ares I booster. The aft skirt, forward skirt, frustum, nose cone, and other hardware were used as currently defined on Shuttle SRB heritage configurations. The performance capability of this booster is optimized for the Ares I vehicle and is not optimum for the Ares V vehicle.

The subsequent booster configuration started with the Ares I booster design. The grain and nozzle designs were re-optimized to assist in satisfying the payload performance requirements for Ares V. The Ares V vehicle needs substantially more impulse during the atmospheric phase of flight than the Core Stage and the Ares I booster can provide. More impulse equates to higher thrust traces versus time and larger propellant weight capacities.

Initially, the Ares V vehicle Core Stage configuration was lengthened to provide more impulse by adding an empty (no propellant) "one-half" segment to the booster design. This length change to the booster permitted the Core Stage to be lengthened to add more propellant. The second iteration added propellant to the empty "one half" segment, and, with the addition to the Core Stage longer tanks provides a substantial additional impulse to the first phase of ascent. Thus the POD configuration is composed of five normal-sized booster segments and one "half segment."

The Ares V booster nozzle configuration has an expansion ratio of 9.3 (currently the same as the Ares I lunar missions). The Ares V booster initial nozzle exit diameter is about 440 cm (173 in). The length of the nozzle is about 86 cm (34 inches) longer than the current Shuttle nozzle.

3.2.1.2 Ares V POD Core Stage

The Ares V Core Stage is a liquid propulsion element that provides thrust during the first five minutes of powered ascent. The Core Stage utilizes a LOX/LH2 oxidizer/fuel combination leveraging much of the Space Shuttle External Tank design. This element stretches 66 m (216 ft) long, has a constant OML diameter of 10 m (33 ft) and consists of both composite (graphite epoxy IM7) dry structures and Al-Li propellant tanks. The sub-systems that make up the Core Stage are the Main Propulsion System (MPS), Aft Skirt/Thrust Structure, LH2 tank, Intertank, LOX tank and Forward Skirt (Figure 10). The Core Stage has a dry mass of 157.6 t (3,499.5 lbm) and can carry a propellant mass of 1,587.3 t (3,499.5K lbm) of useable propellant when fully loaded for ascent. At Core Stage burnout, this element has a mass of 173.9 t (383.4K lbm).

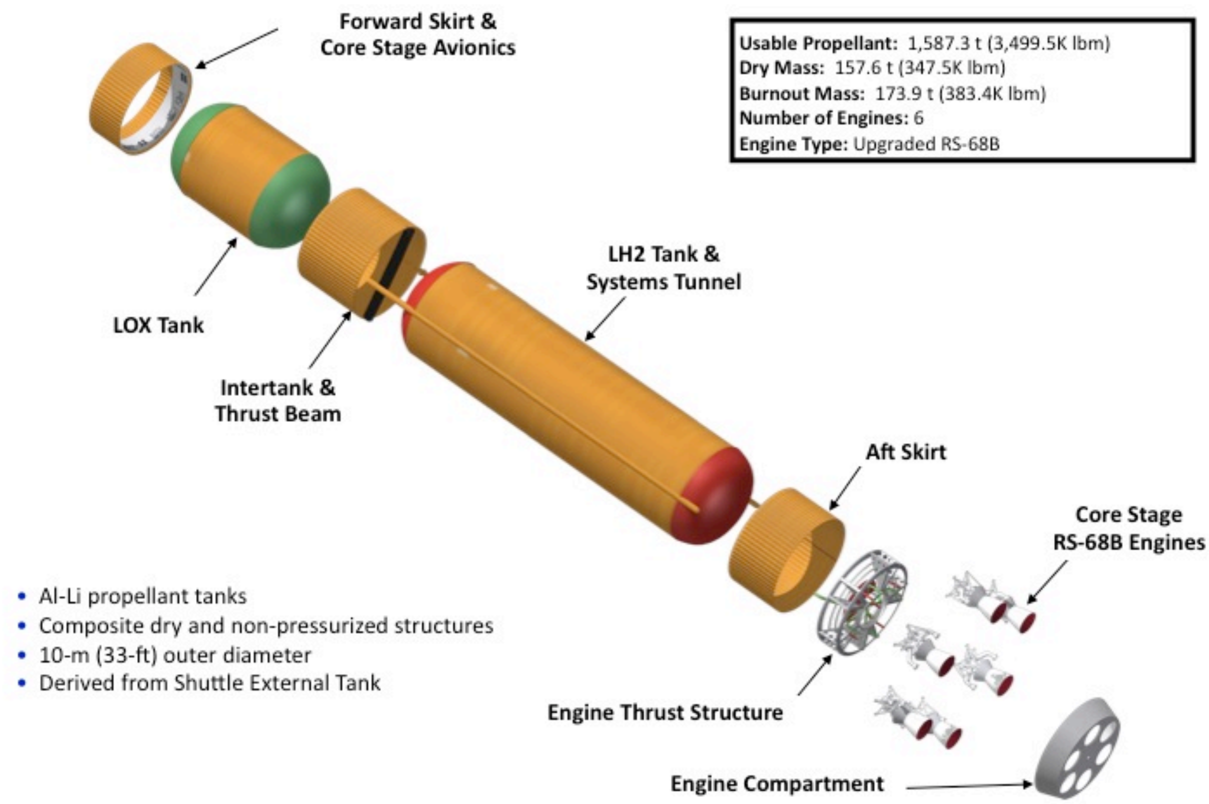

Figure 10 Ares V Core Stage Element View.

The MPS consists of a six-engine RS-68B cluster and the feed system that transports the propellants from the Core Stage LOX and LH2 tanks to the engines. The RS-68B engine is an upgraded version of the RS-68 used on the Boeing Delta IV EELV and shares the performance and safety enhancements of the Air Force-developed RS-68A upgrade. The new RS-68B outputs 3,500 kN (797,000 lbf) of thrust operating at 108% in vacuum; it also provides an Isp of 414.2 seconds.

The Core Stage Aft Skirt is a composite cylindrical structure that joins the MPS/Thrust Structure to the LH2 tank.

The LH2 tank is 41 m (133 ft) long and is constructed of Al-Li barrels and domes. Pressure relief valves are located on both forward and aft domes to assist in propellant settling. A sump at the bottom of the aft dome drains the fuel through a single feedline that goes to the MPS LH2 manifold.

The Intertank physically separates the Core Stage LH2 and LOX tanks and provides a physical interface to the solid boosters. Built with composite materials the Intertank not only carries the weight of the structures above, it also provides the structural interface for the SRB forward attach points. There are two attach fittings on opposite sides of the Intertank which interface with the

SRB forward attach mechanisms; an internal crossbeam joins these two attach fittings and provides structural support for the high loads induced by the solid boosters.

The LOX tank is 16 m (53 ft) long and is constructed of Al-Li barrels and domes. Pressure relief valves are located on both the forward and aft domes to assist in propellant pressurization. A sump at the bottom of the aft dome drains the oxidizer through two feed lines that go to the MPS LOX manifold.

The Core Stage Forward Skirt is the forward-most component on the Core Stage and is attached to the aft end of the Interstage. This component houses the Core Stage avionics used to monitor and control the Core Stage engines and both solid boosters as well as communicate with the avionics system on the EDS Instrument Unit. The Forward Skirt also supports Core Stage separation. Retro rockets evenly distributed around the circumference of this composite skirt support a smooth separation from the EDS.

3.2.1.3 Ares V POD Earth Departure Stage (EDS)

The 51.00.48 EDS is an upper stage propulsion element that provides the sole source of thrust once the solid boosters and Core Stage have separated from the EDS-Altair stack. The EDS has a 10-m (33-ft) outer diameter, measures approximately 23-m (74-ft) long, and is comprised of composite (graphite epoxy IM7) dry structures and Al-Li 2195 propellant tanks. The primary functions of the EDS are to insert the EDS-Altair stack into LEO, provide resources as needed to Altair through the launch phase, perform loiter operations for up to four days in LEO, dock with Orion and perform the TLI burn for the EDS-Altair-Orion stack. The EDS is pressurized to condition the propellant and re-start the J-2X engine for the TLI burn. The primary EDS structures are the Interstage, Loiter Skirt, EDS MPS, Aft Skirt/Thrust Structure, LOX tank, Intertank, LH_2 tank and Forward Skirt. See Figure 13 for a view of the major EDS component and design. The EDS has a dry mass of 24.2 t (53.5K lbm) and carries 251.9 t (555.2K lbm) of useable propellant mass, of which 150 t (330K lbm) is burned during ascent. At EDS burn out, this element has a mass of 26.6 t (58.7K lbm).

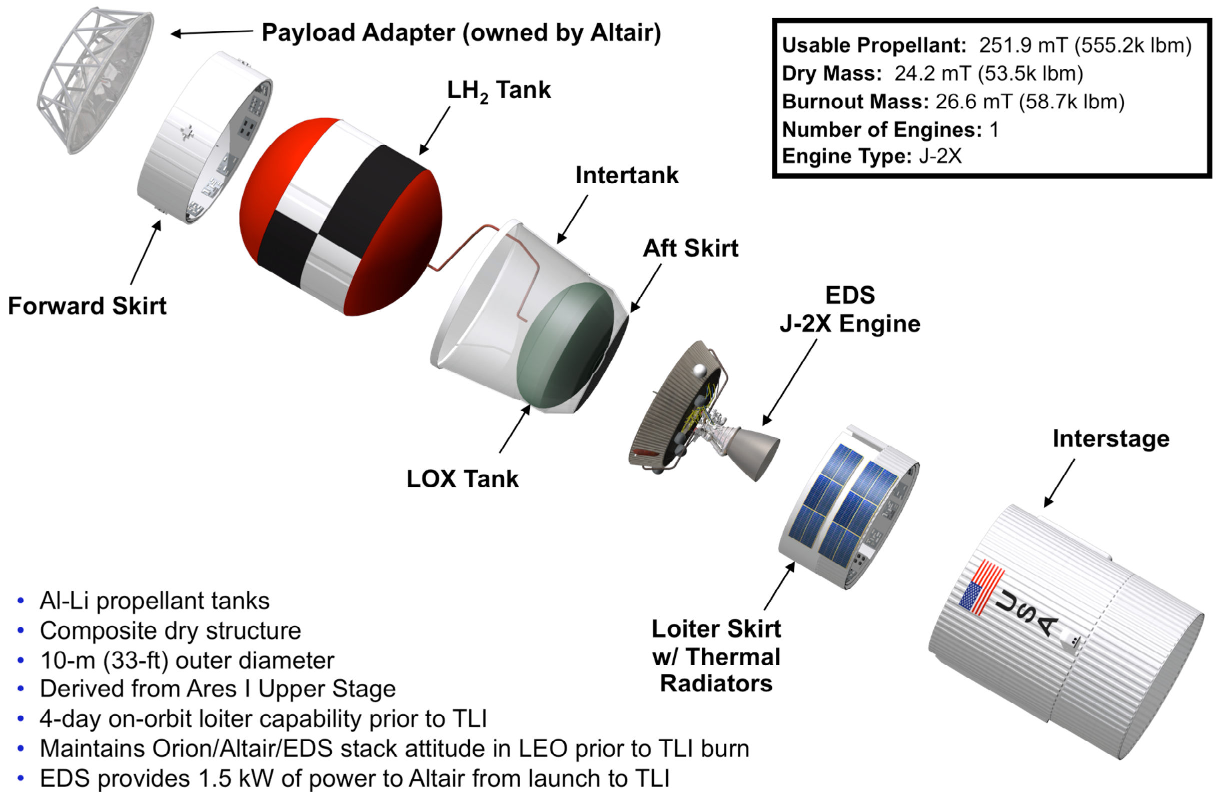

Figure 11 Ares V EDS Element View

The Interstage is a composite cylindrical structure that interfaces with the Core Stage. Together with the Loiter Skirt, the Interstage houses the J-2X engine and its extended nozzle. While segmented to the EDS, the Interstage remains attached to the Core Stage throughout launch. A separation ring at the forward end is activated during Core Stage separation allowing the Core Stage and Interstage to separate together from the EDS-Altair stack.

The Loiter Skirt is a cylindrical structure that encompasses the J-2X engine. It is located between the Interstage and Aft Skirt/Thrust Structure. This composite structure contains fuel cells/batteries and other sub-system resources to maintain the EDS and Altair during its loiter operations in LEO. The LCCR POD concept assumes that the Loiter Skirt is jettisoned just prior to the TLI maneuver.

The EDS MPS provides the needed propulsion for the LEO insertion and TLI insertion burns. The MPS consists of the J-2X engine and the associated feed system, which interfaces with the EDS LOX and LH_2 tanks.

The Aft Skirt and Thrust Structure provide the structural interface between the J-2X engine and the EDS. The Aft Skirt is a short tapered conical section constructed from composite material and accommodates the small diameter of the EDS LOX tank. The Thrust Structure provides the attach points for rigidly mounting the J-2X engine.

The LOX tank is constructed from aft and forward Al-Li domes which together measure 6 m (18 ft) long and 8 m (26 ft) in diameter. The LOX tank can hold up to 202 t (445,000 lbm) of oxidizer. The tank interior contains slosh baffles and a vortex baffle at the outlet. Unlike the Core Stage propellant tanks, the EDS LOX tank must manage its cryogenic propellant to eliminate undesirable propellant loss during the four-day loiter period. To this end, Cryogenic Fluid Management (CFM) technologies will be incorporated into the tank to preserve propellant.

The EDS Intertank separates the LOX and LH2 propellant tanks. It is manufactured from composite materials and tapers from the 10 m EDS outer diameter (at the LH2 Tank) down to the diameter of the LOX Tank.

The LH2 tank Aft Skirt is a short barrel section that joins the Intertank to the LH2 tank. It measure approximately 2 ft long and is made from composite material.

The LH2 tank is comprised of one barrel section and two domes, which together measure approximately 10 m (33 ft) in length. The LH2 tank can hold 40 t (89,000 lbm) of liquid hydrogen fuel. The tank is an Al-Li metallic structure. The tank interior also leverages CFM technologies to prevent propellant boiloff during the four-day loiter period. MMOD shielding is integrated into the external side of the barrel section to protect against the debris environment during loiter.

In the POD, the EDS Forward Skirt houses the avionics system that provides primary data and command and control for the Ares V integrated vehicle throughout all phases of flight. The Forward Skirt provides the primary interface to the payload shroud and adapter.

3.2.1.4 Ares V POD Payload Shroud

The 51.00.48 shroud is a composite structure consisting of a cylindrical barrel section and a nose cone. The shroud measures 22 m (72 ft) in length and 10 m (33 ft) in diameter (across the barrel section). The POD vehicle exhibits a biconic nosecone with a rounded tip. Figure 12 illustrates the POD biconic shape and a candidate ogive shape. This baseline configuration is designated as PFS-1 and features a quad petal design for effective shroud separation. The material construction consists of a composite sandwich with aluminum honeycomb core and painted cork TPS bonded to the outside. The shroud weighs a total of 9.4 t (20,728 lbm) which includes the structure, TPS, and acoustic blankets

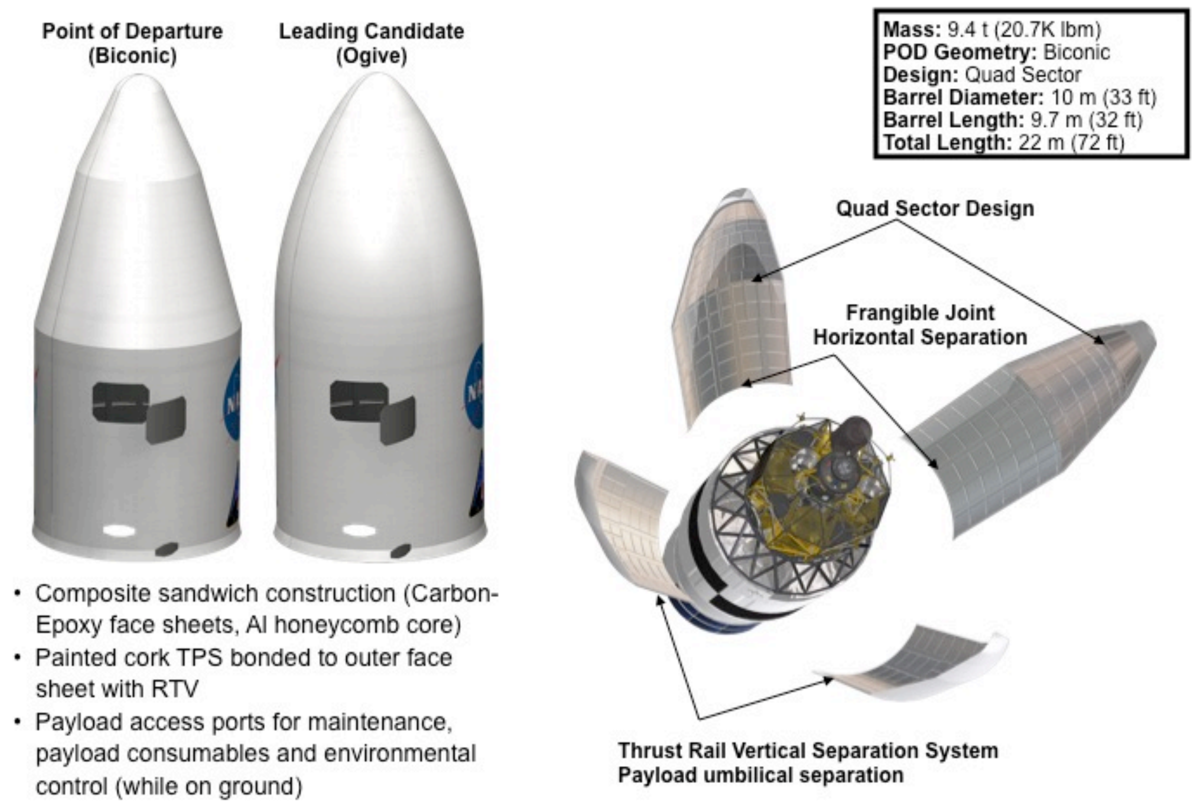

Figure 12 Ares V Shroud Element View.

As part of the first analysis cycle, initial aero and structures models were constructed, and preliminary load cases were defined. Analysis of the PFS-1 shroud includes inertial loads, aerodynamic loads, aero-heating, and acoustic loads. Preliminary sizing of the TPS, structures and subsystems have been performed.

Numerous shapes have been identified as alternatives to the biconic configuration. Preliminary analysis is in progress for the various shapes (see Figure 11 for the shroud shape trade space) and is only presented partially here due to the incomplete status of the analysis. It is anticipated that the analysis will be complete for the next iteration. Future efforts will include completing the shape trade analysis to determine if a more optimized shroud configuration is feasible for Ares V. This trade study will consider all identified driving factors, including mass, payload volume, performance, cost, manufacturing, transportation, etc.

3.2.1.5 Ares V POD Avionics and Software

The Ares V Avionics and Software maintain control over the entire vehicle stack throughout the entire launch profile. The avionics control all aspects of flight including fault recovery and abort conditions as well as any data interfaces to Altair or Orion.

3.2.2 Ares V POD Performance Capability

The performance capability was optimized for the 51.00.48 vehicle by sizing the EDS while maintaining a fixed Core Stage size. The Core Stage remained fixed because the structural attach point of the 5.5-segment booster constrained the position of the Intertank thrust beam thereby constraining the size of the propellant tanks. The mission profile is to launch Altair and a partially loaded EDS into 240 km (130 nmi) circular orbit for rendezvous with Orion, which has been launched on Ares I. After docking, the integrated stack (Orion, Altair, and EDS) assumes to leave from a 185-km (100-nmi) circular orbit for TLI. The J-2X operates for this burn at the lower propellant mixture ratio of 4.5 which lowers the thrust from 1.31M N (294K lbf) used on the Earth–To-Orbit (ETO) portion of the mission to 1.06M N (238K lbf) for TLI, but the Isp increases from 448 s to 449 s. The TLI burn of the EDS J-2X engine is 429.5 s.

The TLI payload capability for the Lunar Sortie DRM using the 51.0.48 concept for a 1.5 launch scenario (rendezvous in LEO with Orion launched on Ares I) is 71.1 t (156,700 lbm).

4.0 Test and Evaluation Strategy

A better understanding of the impacts of the Ares V POD to the Cx architecture, specifically manufacturing and logistics and ground processing, can be achieved through the formulation of the Ares V Test and Evaluation (T&E) strategy. The Ares V team sketched out an initial T&E strategy that addresses system- and element-level test needs, possible test facilities, test schedules and facility construction/upgrade needs, and Ares V-Y flight test objectives. This section discusses the strategy for the primary test areas of integrated vehicle testing, propulsion testing, and flight tests.

A POD T&E strategy was developed for the Ares V vehicle and elements. This initial strategy includes the following elements:

1. Testing is required for the Ares V Core Stage and EDS through development, qualification, design certification, and initial flights.
2. Development and certification testing are required for the RS-68B engines, including component-level testing to verify design modifications from existing versions of the RS-68.
3. Additional testing for the J-2X engines is required to verify requirements associated with on-orbit re-start for TLI burn.
4. Additional qualification motor tests for the SRBs are required based on the 5.5-segment booster design for the 51.0.48 vehicle.
5. Qualification testing must be performed for the payload shroud, including shroud deployment testing in a space simulation (thermal-vacuum) environment.
6. System-level tests need to be conducted to validate environments, performance parameters, and vehicle dynamic response during ascent.

The initial T&E strategy is based on several key assumptions. The 51.00.48 configuration, described in earlier sections of this report, is the basis for determining appropriate system-level and element-level tests. Where possible, the Ares I integrated test plan was used as a guide, including lessons learned from various trade studies conducted early in the Ares I system definition phase. Additionally, a historical survey of test approaches was conducted on Saturn, Space Shuttle, and applicable Expendable Launch Vehicle (ELV) systems development.

Assumptions on test need dates were determined based on projected flight dates and other critical milestones. Delivery of flight hardware for the Ares V-Y flight and full verification of all requirements with test data and test-verified analyses are assumed as key requirements, where appropriate, at the Design Certification Review (DCR). Fabrication of integrated element-level and system-level test articles is assumed to occur following Ares V PDR to allow for sufficient hardware maturity. Note that schedules are subject to adjustments as the Ares V concept matures and Ares I DDT&E progresses.

Based on projected test requirements, a POD facility readiness plan was also developed, which includes projected facility requirements to meet test need dates. Achieving facility readiness for

Ares V DDT&E will require, in some cases, investments in infrastructure modifications, improvements, refurbishment, or construction of new facilities.

Refinement of system-level and element-level requirements will continue through the Ares V SRR. Some additional trade studies for facility and test requirements are defined in this report. Maturation of T&E plans will also include additional definition at the subsystem- and component-level prior to SRR.

Table 1 shows a summary of assumed key driving requirements for Ares V test and evaluation.

Table 1 Assumed Key Driving Requirements for Ares V T&E Strategy

	Verification Requirement	Verification Method
Aerodynamics / SIL / IVGT	Verify the ability of the integrated vehicle to meet mass, performance, and payload insertion requirements.	<u>Verify by Analysis</u> Anchored to Test Data: •Aerodynamic Testing and Database •Induced Environments Testing •Integrated Vehicle Ground Vibration Testing (IVGVT)
	Verify the ability of the control system to meet vehicle performance requirements.	<u>Verify by Analysis</u> Anchored to Test Data: •Aerodynamic Testing and Database •IVGVT •SIL Testing
Propulsion / Flight	Verify integrated operations of the EDS/J-2X system and ability to meet vehicle performance requirements for insertion of orbital payload.	<u>Verify by Analysis</u> Anchored to Test Data: •EDS Sea-Level Propulsion Test •Ares V-Y Flight Validation
	Verify the ability of the EDS to meet on-orbit loiter requirements and re-start of the J-2X engine for TLI burn.	<u>Verify by Analysis</u> Anchored to Test Data: •Orbital Environments Testing •Ares V-Y Flight Validation
	Verify the integrated operations of the core stage/RS-68 system and ability to meet vehicle performance requirements for insertion of orbital payload.	<u>Verify by Analysis</u> Anchored to Test Data: •Core Stage Sea-Level Propulsion Test •Ares V-Y Flight Validation
Structural / Flight	Verify the design, structural integrity, and performance of EDS and core stage metallic cryogenic tanks.	<u>Verify by Analysis</u> Anchored to Test Data: •Proof Pressure Test •Cryo-Structural Testing
	Verify the design, structural integrity, and performance of composite aft skirt, inter-tank, and inter-stage structures.	<u>Verify by Analysis</u> Anchored to Test Data: •Advanced Composite Technology •Development Testing •Structural Test Article Testing
	Verify the design and performance of the payload shroud for deployment of Altair.	<u>Verify by Analysis</u> Anchored to Test Data: •Separation, acoustic, vibration, environmental, and structural loads testing. •Ares V-Y Flight validation

At the Mission Concept Review (MCR) stage, requirements exist only at the CxP architecture level. Key requirements include a requirement for payload mass to orbit and the ability to loiter in LEO for a period of 4 days prior to docking with Orion and executing a TLI burn.

Allocation of the architecture-level requirements to the Ares V system and elements will be performed prior to the Ares V SRR, along with verification methodologies for each system-level and allocated element-level requirement. Requirements have been assumed for purposes of developing an initial strategy for verifying key driving requirements. Verification of the integrated vehicle performance and control system to meet the payload insertion requirement will necessitate testing at the vehicle system-level. Test strategies include integrated vehicle modal testing, avionics and software testing, aerodynamic testing, and other induced environments testing.

Verification of the integrated stage assembly operations (Core Stage and RS-68B engines; EDS and J-2X engines) will necessitate both propulsion and structural development and qualification testing at the integrated stage level. Integrated propulsion test articles are needed for both the Core Stage and EDS to fully verify the operation of the propulsion system during ascent. For the EDS, testing is also needed to verify the ability of the EDS to operate after the on-orbit loiter period. Testing is necessary for the J-2X engine to verify on-orbit re-start capability to qualify key EDS sub-systems in a space environment.

As previously discussed, development and certification of the RS-68B engines and two additional qualification test motors for the solid boosters are included in the integrated test plan. The RS-68B engine will be largely heritage hardware from the existing RS-68 engine, with planned upgrades to support both an RS-68A version (which meets DoD mission needs) and RS-68B for NASA requirements. Thus, the RS-68B test program consists of development testing with rebuilt RS-68 engines and two additional certification engines to verify the design changes.

The requirement to verify the structural design and performance of the Core Stage, EDS, and payload shroud, including cryogenic propellant tanks and composite primary structure, leads to test requirements for structural test articles, proof pressure testing, and payload shroud deployment testing.

In most cases, the verification of system-level and element-level requirements will be by analysis anchored to test data. Ares V-Y is envisioned as a flight validation opportunity for these key verification requirements.

4.1 Ground Rules and Assumptions

Key ground rules and assumptions for the initial Ares V T&E plan are as follows:

1. Fabrication of Core Stage and EDS propulsion test article and structural qualification test articles will occur after the Ares V PDR in order to maximize hardware fidelity of

cryogenic tanks, primary structure, and avionics systems. Note that this schedule assumption requires refinement of manufacturing and assembly time lines in order to meet test need dates.

2. Acceptance testing of both the EDS and Core Stage with integrated J-2X and RS-68B flight engines is required prior to Ares V-Y and Altair-1 flights.
3. Integrated stage propulsion testing must be completed prior to stage acceptance testing with sufficient schedule margin to inform tanking and engine start procedures for acceptance testing and Ares V-Y launch operations.
4. Certification testing for J-2X and RS-68B engines will be completed prior to DCR.
5. The EDS and Core Stage will be manufactured at Michoud Assembly Facility (MAF). (This assumption is subject to change as the acquisition strategy is formulated and detailed manufacturing plans are developed.)
6. The J-2X and RS-68 engines will be integrated with the stage assemblies at MAF before being shipped to Stennis Space Center (SSC) for acceptance testing.
7. The IVGVT, payload shroud qualification testing, payload shroud deployment testing, and EDS orbital environments testing will be completed prior to Ares V-Y.
8. Although key tests will be completed prior to Ares V-Y, full verification of requirements, including test-correlated analytical models, may not occur until DCR prior to Altair-1.
9. Test and facility need dates are based on the flight manifest used during the NASA PPBE 2010 Rev. 0 cycle: Ares I-Y flight in September 2012, Ares I Initial Operational Capability (IOC) achieved with Orion-2 in September 2013, Ares I Full Operational Capability (FOC) achieved with Orion-3 in September 2014; Ares V-Y in June 2018 and first human lunar mission with Altair-1 in December 2018. Note that schedules are subject to change as the flight manifest is adjusted and the CxP matures through Ares I DDT&E and Ares V concept development.

4.2 Historical Benchmarking

The development of Ares V T&E plans was guided by historical benchmarking from Saturn, Shuttle, and EELV programs, as well as guidance from Ares I DDT&E plans. The significant propulsion and structural test programs are summarized below.

Propulsion Testing:

1. Saturn conducted development testing for all three integrated stages and engines (S-IC/F-1, S-II/J-2, and S-IVB/J-2).
2. Shuttle conducted development testing with a total of 10 development engines for the SSME. The Shuttle Main Propulsion Test Article (MPTA) consisted of a total of 18 tests with 11,000 s of total hot-fire test time.
3. Delta IV conducted development testing with the common booster core and RS-68 engines.
4. The Ares I team plans to conduct development and certification testing for the J-2X engine at both sea-level and altitude simulation conditions.

5. Ares I plans to conduct an MPTA program for the upper stage to verify operations for key subsystems, integrated stage operations, and fill and drain procedures.
6. Saturn conducted acceptance testing ("Green Runs") of all three flight stages. Ares I plans to conduct acceptance testing of flight stages for the first three flights before evaluating the need to continue with this requirement.
7. Shuttle conducted acceptance testing of the SSMEs, including a 1.5-s start sequence verification, a 100-s calibration test, and a 520-s full-duration mission simulation burn.
8. Atlas V conducts acceptance testing of both RD-180 and RL-10 engines.

Structural Testing:

1. Saturn conducted static testing of all skirts and interstages.
2. Saturn conducted cryo-structural testing for all propellant tanks.
3. The Shuttle ET conducted static testing of the LH_2 tank, LOX tank and the Intertank. The Intertank test article was a full-scale flight article with simulators for the LH_2 and LOX tank interfaces. Each tank simulator contained a Liquid Nitrogen (LN_2) torus near the interface with the Intertank to simulate the cryogenic effects of the propellant tanks at these locations. The LH_2 tank was tested with cryogenic propellants and the LOX tank was tested with Barium Sulfate ("driller's mud") and corrosion-inhibited water.
4. Later in the Space Shuttle Program, an Aluminum-Lithium Test Article (ALTA) was developed to verify the ability of the Super Lightweight Tank (SLWT) design to withstand compression buckling. The ALTA was a full-diameter, but shortened, cylindrical barrel section tested at ambient conditions.
5. Ares I plans to conduct static structural testing with multiple development and qualification test articles. Full-scale cryo-structural testing (combined LOX and LH_2) of the upper stage propellant tanks is necessitated by the common-bulkhead design for Ares I.

4.3 Propulsion Testing

4.3.1 EDS Propulsion Test Approach

The EDS propulsion test plan includes both integrated stage testing and additional J-2X engine testing to fully verify all requirements and qualify the design hardware prior to flight.

A MPTA for the EDS will serve as the development test bed for integrated stage and J-2X engine operations. Objectives will include verification of propellant management operations, Main Propulsion System (MPS) performance, TVC operations, pressurization system performance, engine start, and main stage operations. The MPTA will be a full-scale flight-design stage, but may have some design differences. A J-2X production engine will be used for EDS MPTA testing.

"Delta certification" testing for the J-2X engine will be conducted to verify the ability of the engine to re-start after LEO loiter. Prior to Ares I IOC, the J-2X engine will be certified for all requirements, except for a specific subset dealing with on-orbit operations unique to Ares V. The engine start sequence and a short duration burn will be performed in a space simulation (thermal-vacuum) environment.

EDS orbital environments testing is also necessary to validate aspects of CFM during LEO loiter and to verify the ability of the MPS to supply the J-2X engine with the correct "start box" conditions for on-orbit re-start. Other aspects of this testing may include verification of on-orbit power requirements, thermal conditioning of key subsystems, TVC actuation, and operation of engine controllers in a space environment. The initial test plan assumes that this objective can be accomplished with a subscale test article that includes the necessary representative subsystems.

A requirement for hot-fire acceptance testing of the flight stages is assumed beginning with the Ares V-Y vehicle. The number of flights for which this requirement will be carried is TBD.

4.3.2 Core Stage Propulsion Test Approach

Similar to the EDS, the Core Stage propulsion test approach includes necessary testing to certify the RS-68B engines for Core Stage operations and verify all requirements associated with integrated stage operations and performance.

A development and certification test program is planned for the RS-68B engines. The DDT&E plan uses one development engine designed to validate design upgrades incorporated in the B-version of the RS-68, plus two certification engines. These three engines, along with three additional production engines, will also be used in Core Stage development testing.

A Core Stage MPTA is also planned. This test article will provide a test bed for propellant management; performance of MPS, TVC, and pressurization subsystems; engine start; and main stage operations. A requirement for hot-fire acceptance testing of the flight stages is also assumed starting with Ares V-Y. The number of flights for which this requirement will be carried is currently To Be Determined (TBD).

4.3.3 Propulsion Test Facilities

Implementation of the propulsion test program for EDS and Core Stage DDT&E will require full use of the Agency's large-scale propulsion test capabilities, including facilities at MSFC, SSC, and GRC. Table 7 shows a summary of facility utilization for Ares I and Ares V, with significant facility modifications anticipated to achieve facility readiness.

Many of the same facilities used for Ares I DDT&E will be used for Ares V. Therefore, the initial facility utilization plan must consider the need for facilities required for development, acceptance, and qualification testing leading to Ares I IOC as well as potential needs for anomaly resolution and sustaining engineering once Ares I enters the production phase. Note that test and facility need dates are established per the ground rules and assumptions on flight manifest dates described previously. Changes in flight dates as both vehicles mature may require revisiting facility utilization plans and schedules.

Some facilities will require refurbishment, modifications, or construction to support Ares V need dates and capabilities. Table 2 shows the Ares I projected need (yellow), projected facility modification requirements (red), and projected Ares V usage (blue).

Table 2 Projected Ares I and Ares V Propulsion Test Plan.

Test Facility	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
MSFC Test Stand 4670	Upper Stage MPTA Development Testing and Anomaly Resolution				Available as Option for Continued Upper Stage Testing			
SSC A-1 Test Stand	J-2X DDT&E							
SSC A-2 Test Stand	J-2X DDT&E		Conversion			EDS MPTA	EDS Sea-Level	
SSC A-3 Test Stand	J-2X DDT&E		J-2X Acceptance			J-2X Delta Certification		
SSC B-1 Test Stand	Data System Modifications		RS-68B Development			RS-68B Acceptance		
SSC B-2 Test Stand	Off Stand Preparation		US Acceptance Off Stand Prep		Conversion	Core Stage Testing and Acceptance		
GRC Spacecraft Propulsion Research Facility (B2)	Facility Refurbishment				J-2X and EDS Orbital Environment Testing			

4.4 Structural Test Facilities

The initial test plan uses existing structural test facilities at MSFC with some modifications required to support EDS and Core Stage structural strength testing. The two main facilities identified to support Ares V testing are the Load Test Annex (LTA) (MSFC Building 4619) and the Hazardous Structural Strength Test Facility (MSFC Building 4572). A summary of facility utilization for key structural test requirements is shown in Table 3.

Table 3 Projected Ares I and Ares V Structural Test Plan.

Test Facility	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
MSFC Dynamic Testing (4670)	Ares I IVGVT			Stand Modifications		Ares V IVGVT		
Core Structural Testing (4572 Cryo & 4619 LTA)	US Qual	Facility Modifications			Core Structural Qualification Testing			
EDS Structural	US Qual	Facility Modifications			EDS Structural Qualification			

Testing (4572 Cryo & 4619 LTA)			Testing	
Shroud Testing (GRC Spacecraft Propulsion Facility)			Shroud Testing	

4.5 Aerodynamic Characterization Tests

The Ares V aerodynamic characterization plan builds on the experience and knowledge obtained from the Ares I and Ares I-X programs. To fully characterize the Ares V aerodynamics, three vehicle configurations will be examined:

1. Full vehicle (the core with attached SRBs)
2. Core Stage in proximity to the separated boosters
3. Core Stage alone

These configurations will be tested in ground test facilities and analyzed using state of the art aerodynamic Computational Fluid Dynamics (CFD) capabilities. The Ares V vehicle is more complex than the Ares I, thus requiring additional testing and analyses to adequately characterize the aerodynamics.

Two lessons learned from the Ares I program will apply to the Ares V program. The first is that early testing and CFD studies are essential in order to insert high fidelity aerodynamic data into early Design Analysis Cycles (DACs) to facilitate design decisions. The second lesson is that the plan will leverage both experimental testing and CFD to produce high-quality, validated aerodynamic models. The goal is to use the technique, experimental or computational, that provides the required data in the most efficient manner. As an example, force and moment databases are constructed using test data and validated using CFD because obtaining the data using CFD alone would be time- and cost-prohibitive. Similarly, loads databases consist primarily of CFD data and are validated using test data because load testing is more complex and expensive.

4.6 Ares V-Y Flight Test Objectives

Ares V-Y is scheduled for June 2018 and is viewed as an opportunity to validate aspects of Ares V vehicle, stage, and subsystem performance prior to human lunar return. The Ares V-Y configuration is assumed to be a flight-design Core Stage, EDS, SRBs, and payload shroud with production RS-68B and J-2X engines. The mission profile for Ares V-Y assumes a full SRB burn with booster separation, a full Core Stage burn, stage separation, full EDS ascent burn, shroud separation, and insertion of the EDS into LEO. The full scope of on-orbit test objectives for the Ares V-Y mission are subject to further study, but, at a minimum, it is assumed that these will include an evaluation of EDS on-orbit performance, CFM, and an on-orbit restart of the J-2X engine.

At the time of the MCR, the assumed payload is a structural analogue of the Altair lunar lander. Further study will be conducted to determine the feasibility of including a production Altair as a flight test article and adding test objectives such as Altair separation in LEO and Altair propulsion operations. Ares V-Y also provides an opportunity to validate logistics, stacking, assembly, servicing, ground testing, tanking procedures, and other aspects of pre-launch operations at the launch site.

4.7 Additional Element and Subsystem Testing

The incorporation of a modified 5.5-segment SRB carries a requirement of three additional static firings of this motor in order to re-qualify this hardware for Ares V operations. The initial plan will be to conduct these tests in the fiscal year 2016–2017 time frame to support the Ares V-Y flight.

Additional subsystem level testing will be defined as the concept designs mature.

5.0 Forward Work

Significant concept design work has been accomplished for the Ares V LV. During the course of the LCCR discussions regarding both of these concepts with NASA Headquarters, the CxP, and other Level III Projects, several key issues were identified as forward work for the Ares V team to accomplish. This section describes the key issues and forward work identified for future follow-up.

5.1 Flight Manifest Increase Assessment

An important LCCR exit directive assumed an Ares V outyear (post 2020) manifest flight rate of four flights per year. This was a change to the LCCR entry manifest that assumed an outyear flight rate of two flights per year. Preliminary analysis indicates that a flight rate of four flights per year could be achieved starting in 2024 by ramping from two to three flights per year in 2021 through 2023. Figure 13 outlines the proposed changes.

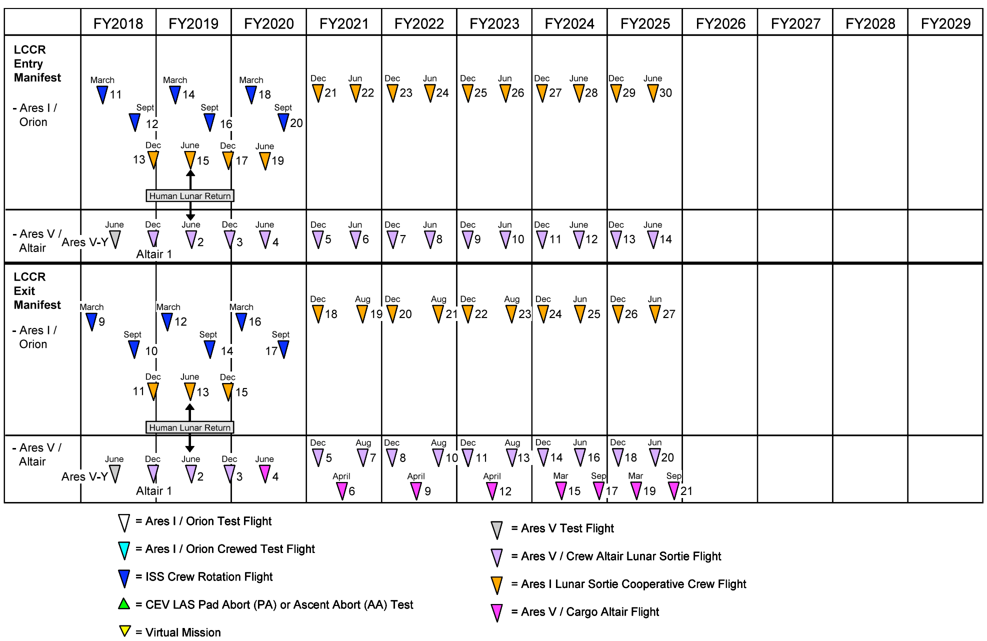

Figure 13 Preliminary Ares V Flight Manifest (Ramp Up to 4 Flights/Year).

The NASA Administrator indicated that the flight manifest would need to increase from two Ares I/Ares V flights per year to four flights per year to sustain a meaningful presence on the Moon. The CxP will investigate the impacts to increasing the flight rate.

5.2 Ares V Flight Test Objective Re-evaluation

The NASA Administrator expressed interest in exploring the possibility of leveraging the Ares I flight tests as a possible opportunity for implementing testing for the Ares V. The CxP will assess which Ares V flight test objectives can be accomplished during the Ares I flight tests. This assessment also includes understanding the impacts to the Ares V flight manifest/schedule.