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Refining the Ares V Design to Carry Out NASA's Exploration Initiative

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Abstract

NASA's Ares V cargo launch vehicle is part of an overall architecture for U.S. space exploration that will span decades. The Ares V, together with the Ares I crew launch vehicle, Orion crew exploration vehicle and Altair lunar lander, will carry out the national policy goals of retiring the Space Shuttle, completing the International Space Station program, and expanding exploration of the Moon as a steps toward eventual human exploration of Mars.

The Ares fleet (Figure 1) is the product of the Exploration Systems Architecture study which, in the wake of the Columbia accident, recommended separating crew from cargo transportation. Both vehicles are undergoing rigorous systems design to maximize safety, reliability, and operability. They take advantage of the best technical and operational lessons learned from the Apollo, Space Shuttle and more recent programs. NASA also seeks to maximize commonality between the crew and cargo vehicles in an effort to simplify and reduce operational costs for sustainable, long-term exploration.

Figure 1. The Ares V Cargo Launch Vehicle (left) and Ares I Crew Launch Vehicle (right) will form the backbone of America's new space fleet. (NASA artist's concept)

The Ares I is designed to carry the Orion crew exploration vehicle and its crew of 4 to 6 astronauts. It comprises a Space Shuttle-derived 5-segment Solid Rocket Booster (SRB) and a new upper stage powered by the Apollo heritage J-2X liquid oxygen/liquid hydrogen (LOX/LH_2) engine. The Ares V is designed to carry the lunar lander or other supplies to support future exploration missions. The Ares V comprises a Core Stage, powered by a cluster of RS-68 LOX/LH_2 engines, 2 SRBs similar to the Ares I first stage, and a new Earth departure stage (EDS) powered by the J-2X engine.

The Ares Projects Office (APO) in 2006 and early 2007 used "seed money" from Congress to perform early engineering analyses on the mission, trajectory, and design of the Core Stage. Since that effort concluded, a variety of programmatic and technical activities have been conducted at NASA's Marshall Space Flight Center, as well as other NASA centers around the country.

Ares V is a cornerstone of the lunar exploration missions, and will fly in support of crewed missions and cargo missions to various locations on the lunar surface. In addition, Ares V will be extensible to crewed and cargo missions to Mars, and is being evaluated by various scientific, exploration, and governmental customers for additional heavy lift applications. A significant challenge in this endeavor is to create a sustainable infrastructure for heavy lift by creating an Ares V capability focused on the initial lunar missions, while still applicable to as many other mission sets as possible. To meet this objective, designers are applying mission-level optimization trades into the systems engineering process as early as possible as the design is refined. They also are working with the many stakeholders that have interest in the advantages of heavy lift.

This paper will update the international community on progress to date on the development of the Ares V, including the design processes and tools used to help refine the vehicle and its mission, as well as results of the latest design trade studies.

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REFINING THE ARES V DESIGN TO CARRY OUT NASA'S EXPLORATION INITIATIVE

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ABSTRACT

NASA's Ares V cargo launch vehicle is part of an overall architecture for U.S. space exploration that will span decades. The Ares V, together with the Ares I crew launch vehicle (Figure 1), Orion crew exploration vehicle, and Altair lunar lander, will carry out the national policy goals of retiring the Space Shuttle, completing the International Space Station, and expanding exploration of the Moon as a steps toward eventual human exploration of Mars. A significant challenge in this endeavor is to create a sustainable infrastructure for heavy lift via Ares V, which is focused on the initial lunar missions, while still applying that capability to as many other mission sets as possible. To meet this objective, designers are applying mission-level optimization trades into the systems engineering process as early as possible as the design is refined. The Ares team also is working with the many stakeholders that have an interest in heavy lift. This paper will provide the international community insight into the systems development trades used to mature the Ares V design from the original concept to the current point-of-departure design, including key driving requirements and decisions used to refine the launch vehicle and its mission.

Figure 1. The Ares V Cargo Launch Vehicle (left) and Ares I Crew Launch Vehicle (right) will form the backbone of America's new space fleet. (NASA artist's concept)

I. Introduction

The 2004 Vision for Space Exploration, which would later become incorporated into an official U.S. Space Exploration Policy, called for NASA to retire the Space Shuttle fleet in 2010, develop and fly its replacement by 2015, complete the International Space Station, and return humans to the Moon by 2020 to establish a permanent human presence in preparation for human exploration of Mars. NASA responded in 2005 with the Exploration Systems Architecture Study (ESAS) to create a "system of systems" to accomplish these tasks. One of the study objectives was to define top-level requirements and configurations for crew and cargo launch systems to support the lunar and Mars exploration programs. A set of Design Reference Missions (DRMs) was defined – three for ISS missions, three for lunar missions, and one for Mars exploration. Ground rules and assumptions were established, based on management guidance, internal and external constraints, design practices, and existing requirements. Among those were separation of crew from large cargo to the maximum extent practical, permanent human presence and global access to the Moon, and no in-space EVA required. The vehicle components of the Constellation Program (CxP) architecture are shown in Figure 2.

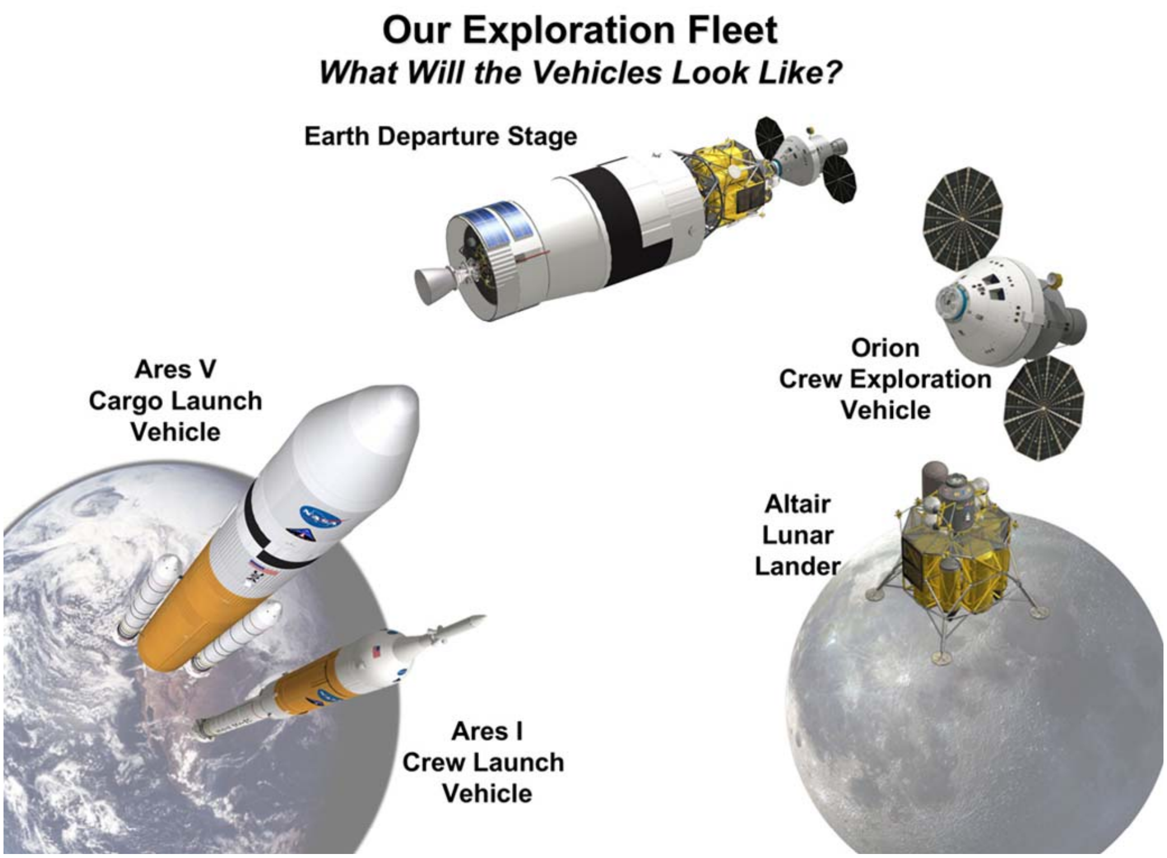

Figure 2. Launch Vehicles and Spacecraft Components of the Constellation architecture.

The Ares I was created as the crew launch vehicle to carry the Orion crew exploration vehicle and its crew of 4 to 6 astronauts. It comprises a Space Shuttle-derived 5-segment Solid Rocket Booster (SRB) and a new Upper Stage powered by the J-2X liquid oxygen/liquid hydrogen (LOX/LH_2) engine. The Ares V was created as a large cargo vehicle designed to carry the Altair lunar lander or other supplies into orbit and send them, as well as the Orion to the Moon. The Ares V comprises a Core Stage, powered by a cluster of six RS-68 LOX/LH_2 engines, two 5.5-segment SRBs similar to the Ares I first stage, and a new Earth Departure Stage (EDS) powered by the J-2X engine. Both Ares vehicles are undergoing rigorous systems design to maximize safety, reliability, and operability. They take advantage of the best technical and operational lessons learned from the Apollo, Space Shuttle, and more recent programs. NASA also seeks to maximize commonality between the crew and cargo vehicles to simplify and reduce operational costs for sustainable, long-term exploration.

A key ground rule established during ESAS for the Ares vehicles was to use proven technologies, components, and infrastructure from the Saturn, Space Shuttle, and contemporary launch vehicle programs, as well as seeking commonality where feasible between the Ares launch vehicles to minimize development and operational costs and to improve safety and reliability. 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 also will share the J-2X engine and various subsystems now being developed for the Ares I Upper Stage. The Ares V design also employs an upgraded version of the commercial RS-68 engine now used on the Delta IV. In the case of all those common components, the Ares V application will require modifications for the Ares V mission that to ensure ongoing interfaces with the relevant hardware and management organizations. That commonality is illustrated in Figure 3.

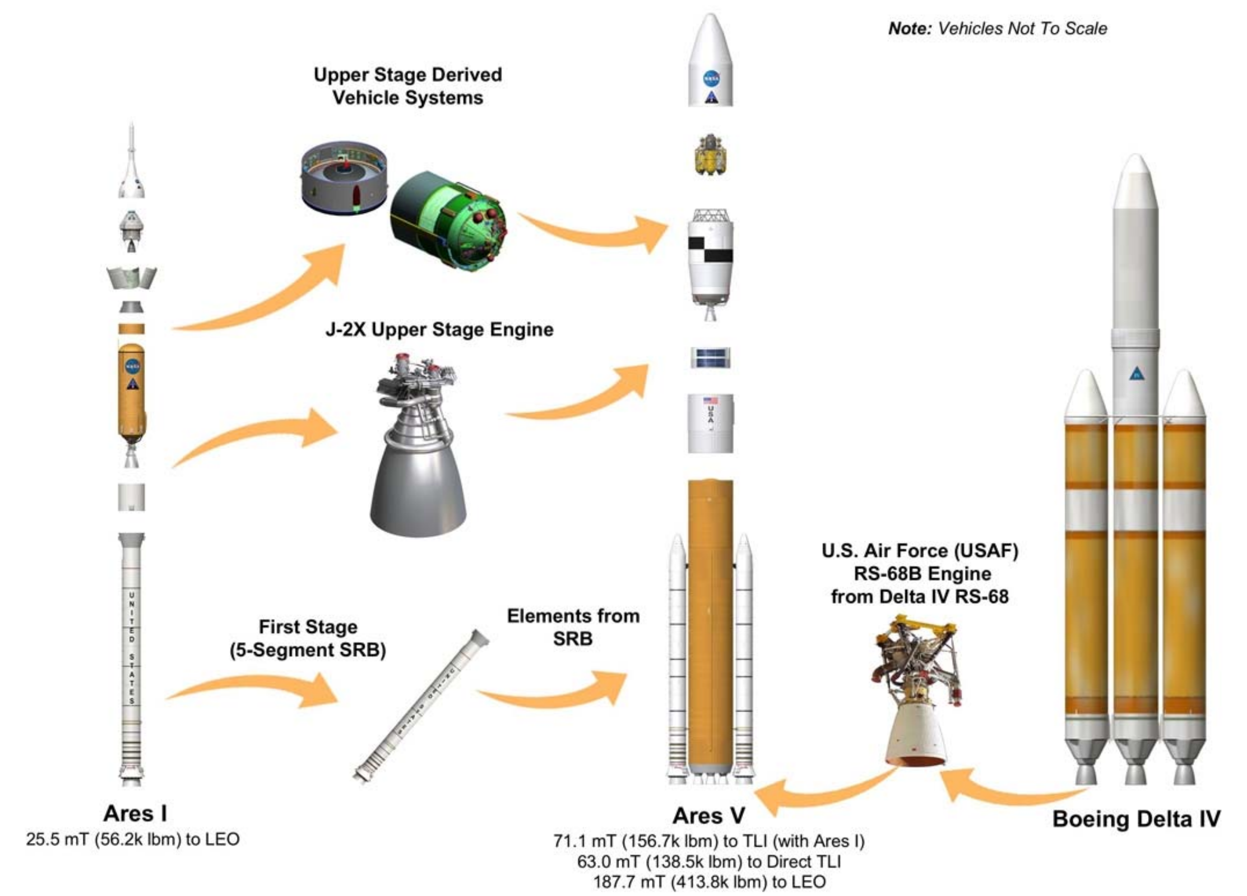

Figure 3. Heritage Systems Utilized on Ares V.

In the profile for the Lunar Sortie (crewed) DRM, (Figure 4), the Ares V launches from Kennedy Space Center (KSC), FL. Following booster and Core Stage separation, the Ares V EDS engine ignites at altitude followed by separation of the payload shroud. Shroud separation occurs last in the staging sequence prior to reaching Low Earth Orbit (LEO) to avoid re-contact with the launch vehicle stack. The EDS delivers the EDS-Altair stack into a stable LEO orbit. Concurrently, the Orion crew exploration vehicle, launched by the Ares I, performs a rendezvous and dock with the Altair. After successful docking, the EDS conducts a system checkout and then re-ignites its engine to perform the trans lunar injection (TLI) burn and to send the mated EDS-Altair-Orion stack en route 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 minutes after Ares I, with 3 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.

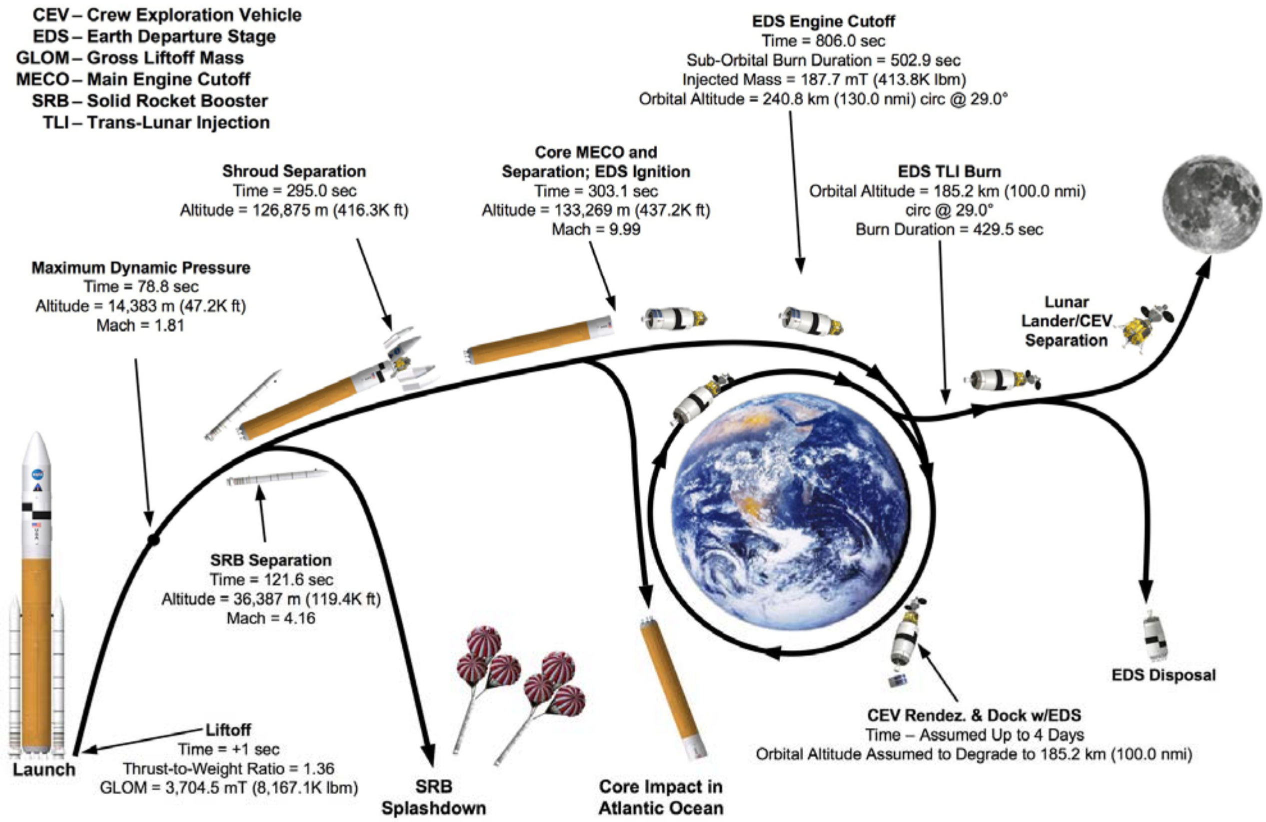

Figure 4. Ares V Launch Profile for the Lunar Sortie Mission.

II. The Ares V Systems Design Challenge

Ares V is the cornerstone to future exploration beyond LEO. It will support crewed and cargo missions to the Moon. In addition, Ares V must be extensible to crewed and cargo missions to Mars. It also is a national asset that may be of interest to potential users who could benefit from the unprecedented payload mass and volume capabilities of Ares V. In order to meet the heavy lift needs of the Constellation Program, the Ares V team is assessing a wide range of vehicle concepts which meet the performance and reliability requirements of the Constellation Program and interface with the other systems – launch vehicles, spacecrafts and ground-based infrastructure – comprising the Constellation architecture. During this initial phase of concept design, the Ares V team is formulating a concept of operations, establishing new vehicle requirements, refining existing requirements, and addressing interface issues with Orion, Altair, and Ground Operations prevalent during ground processing and flight. Through a variety of forums, the Ares V team is building an understanding of the conceptual and performance needs of other non-Constellation missions.

The purpose of the Ares V concept design work is to establish the concept of operations, the core set of performance requirements plus margin, and a viable vehicle concept which also supports interfaces to other Constellation systems. To this end, the Ares V team is performing vehicle-level concept trades and mission sensitivity analyses. The vehicle concept trades assess the ability of various design concepts to meet the current requirements plus desired performance margins. The mission sensitivity analyses assess the impacts to the vehicle concept arising from the interactions with Altair and Orion during LEO loiter. Results from the mission sensitivity analyses are fed back into the vehicle concept trades to assess impacts to overall performance of the vehicles.

The starting point for Ares V concept design is the Constellation Architecture Requirements Document (CARD), which provides the mass requirements for both the Lunar Sortie (crewed) and Lunar Cargo (automated) DRMs. The requirements are shown graphically in Figure 5 and discussed below.

Lunar Sortie Mission			
CARD Requirement	**Mass (t)**	**Mass (lb_m)**	**Derived Performance Rqt.**
Orion [CA4139]	20.2	44,500	
Crewed Lander [CA0836]	45.0	99,208	
Total TLI [CA0848]	66.9	147,575	Derived TLI > 66.9 t
	45.0	99,208	Derived ETO > 45.0 t

Lunar Cargo Mission			
CARD Requirement	**Mass (t)**	**Mass (lb_m)**	**Derived Performance Rqt.**
Cargo Lander [CA5231]	53.6	118,168	
Total TLI [CA0847]	54.6	120,372	Derived TLI > 54.6 t
Total ETO Goal [CA0847]	54.6	120,372	Derived ETO > 54.6 t

Figure 5. Key Ares V Performance Requirements for Lunar Crew and Lunar Cargo Missions.

For the sortie mission, the CARD specifies an Orion control mass of 20.2 metric tons (t) (44,500 lb) and a Lunar Lander control mass of 45t (99,208 lb). The total TLI payload requirement is 66.9t (147,575 lb). The Lunar Sortie mission assumes a LEO destination orbit of 130 nautical miles (nmi) at 29 degrees inclination. The TLI maneuver begins at a minimum 100 nmi altitude with a ΔV requirement of 3,175 meters per second (m/s) plus gravity loss.

For the cargo mission, the CARD specifies a Cargo Lander control mass of 53.6t (118,168 lb) and a total TLI payload mass of 54.6t (120,372 lb). The Lunar Cargo mission assumes a phasing orbit Earth-To-Orbit (ETO) destination. Because the Orion is not part of the cargo mission operations concept, a loiter requirement is unnecessary; however a few revolutions in LEO are anticipated to allow for the lunar launch window and EDS and Cargo Lander checkout prior to the TLI burn. Further CARD requirements are shown in Figure 6.

It is worth noting that the Saturn V TLI payload capability was 48.6t (Apollo 17). The Ares V TLI requirement exceeds the Saturn V rocket's capability by 31 percent.

CARD Req't	Requirement	Rationale
CA0391-HQ	The CaLV shall utilize twin shuttle-derived 5-segment SRBs along with a core stage that employs 5 modified RS-68 engines for first stage propulsion.	◆ Draws Performance Constraints around Booster Selection and Core Stage Design ◆Boosters and Core Stage Provide ~70% of Detla V for LEO Insertion
CA0847-PO	The CaLV EDS shall deliver at least 66,939 (TBR-001-076) kg (147,266 lbm) from Earth Rendezvous Orbit (ERO) to the start of the Trans-Lunar Coast (TLC) for crewed lunar missions.	◆Defines TLI Payload most strenuous performance parameter ◆TLI Payload Sizes EDS
CA0836-PO	The LSAM shall have a Control Mass of 45,000 (TBR-001-075) kg (99,180 lbm) at the time of launch for Lunar Sortie and Lunar Outpost crew missions	◆Defines LEO Payload for Crew Mission ◆Contribute ~2/3 Mass for TLI Payload ◆TLI Payload Sizes EDS
CA4139-PO	The CEV shall have a Control Mass of 20,185 (TBR-001-159) kg (44,500 lbm) at the time of CaLV rendezvous.	◆Contribute ~1/3 Mass for TLI Payload ◆TLI Payload Sizes EDS
CA0051-PO	The CaLV EDS shall provide a minimum translational delta-V of 3,150 (TBR-001-258) m/s (10,335 f/s) for the TLI for crewed lunar missions.	◆Defines Delta V thus propellant Needed for Delta V ◆TLI Delta V Sizes EDS
CA0850-PO	The CaLV EDS shall meet its requirements after loitering in low Earth orbit (LEO) at least (TBD-001-975) days after orbit insertion for crewed lunar missions.	◆Defines Propellant Reserves for EDS Stage ◆Major Factor in subsystem Selection and Design for EDS
CA0282-PO	The CaLV shall deliver at least 125,000 (TBR-001-220) kg (275,578 lbm) to a (TBD-001-072) Earth orbit for Mars exploration missions.	◆Defines Mars Mission Max Payload per launch ◆Orbit and Payload size the Ares V
CA3215-PO	The CaLV shall launch cargo into a (TBD-001-565) Earth orbit for Mars missions.	◆Further defines performance capability of Ares V

Blue = All Missions Grey = Lunar Requirements Red = Mars Requirements

Figure 6. Additional CARD Requirements for Ares V.

In addition to the CARD, the Ares V team has also considered other inputs including various mission and performance ground rules and assumptions, historical data, standard models, and NASA design standards. All of these considerations are factored into the point-of-departure (POD) vehicle modeled in the vehicle analysis tools used for the performance trades – the Integrated Rocket Sizing (INTOS) program, Launch Vehicle Analysis (LVA) program, and the Program to Optimize Simulated Trajectories (POST) – as well as the analysis applications used for the mission sensitivity analyses. Figure 7 illustrates the iterative process used to perform the concept vehicle performance trade studies.

However, several key design issues were either left "TBD" (to be determined) or provided no requirement at all. Among those were: LEO loiter duration, attitude control, injection altitude, power requirements from Altair and Orion, as well as payload shroud-derived requirements. The systems design process had to account for those in its studies. In addition, Ares had to account for "unknown unknowns' in its technical growth and margins approach. Based on previous NASA and industry experience, Ares had to develop a payload reserve margin based on factors such as ullage, motor performance knockdown factors, normal day of flight, winds aloft, trajectory dispersions, and other factors.

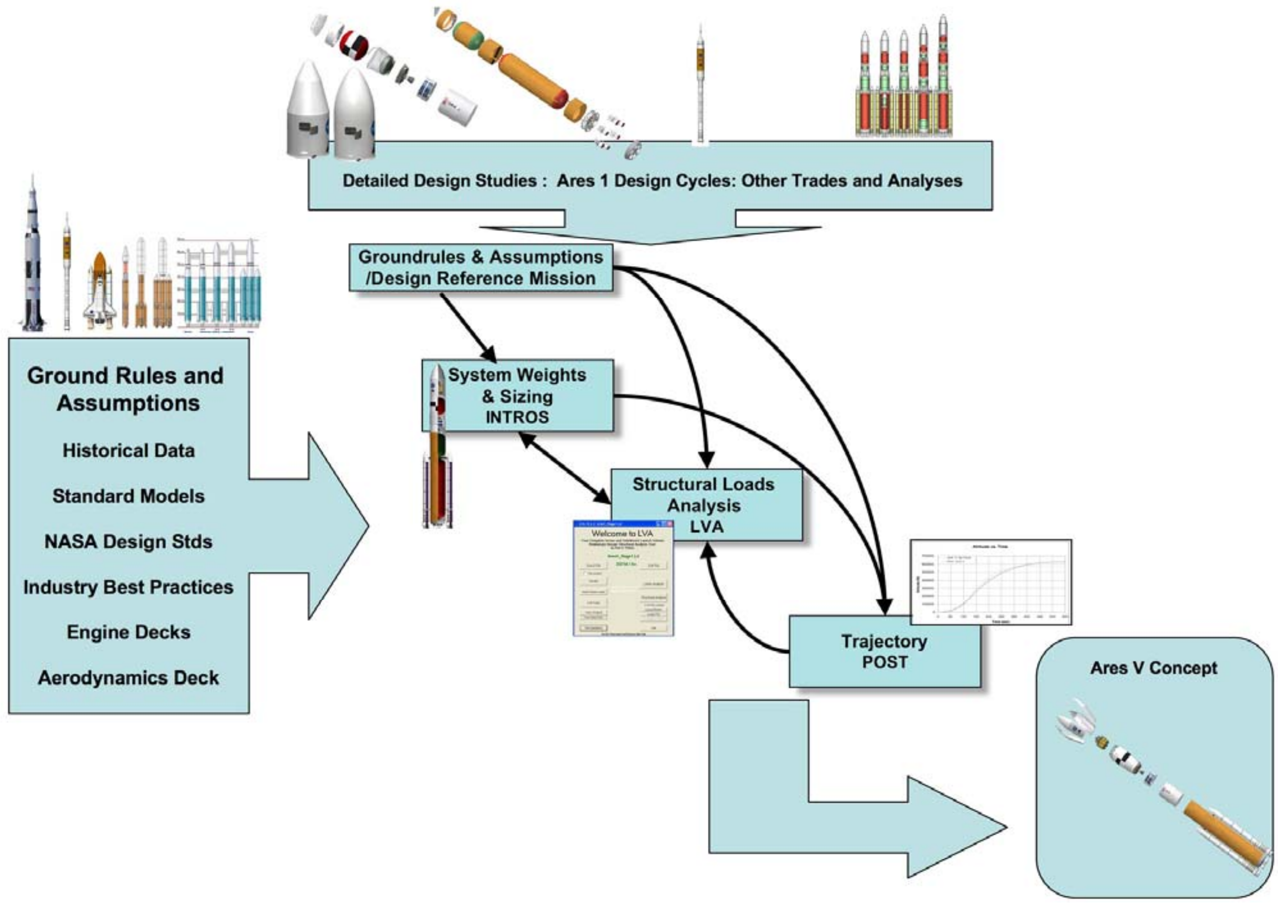

Figure 7. The Ares V design process.

The first designs for a heavy-lift vehicle that would come to be dubbed Ares V were, as stated earlier, studied during the ESAS. From ESAS through the most recent architecture definition – the Lunar Capabilities Concept Review (LCCR) – the NASA design team has studied more than 1,700 Ares V configurations. An effort to illustrate the breadth of the design trades associated with those configurations from 2005 to 2008 is shown graphically in Figure 8.

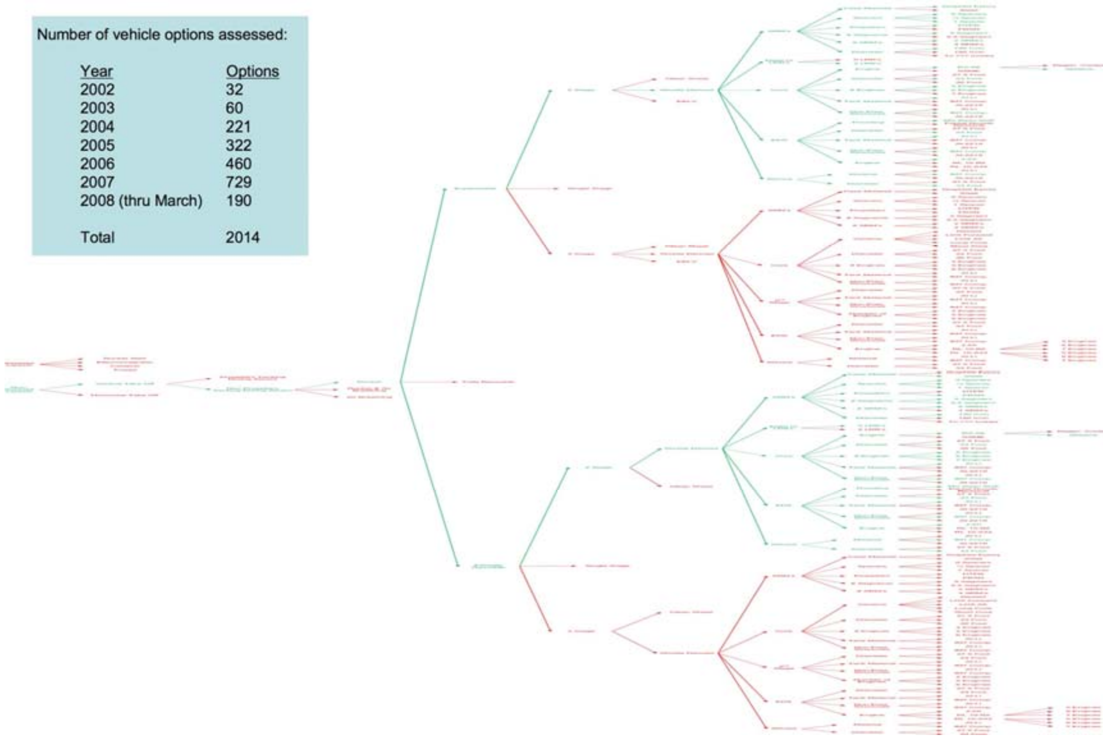

Figure 8. Integrated Trade Tree – ESAS to LCCR.

A more focused view of the major design milestones in Ares V development history is shown in Figure 9 below, beginning with the original ESAS concept and ending with the LCCR Trade Space Options and Recommended POD, subsequently approved by the Constellation Program. These trades are discussed in greater detail in Section III below.

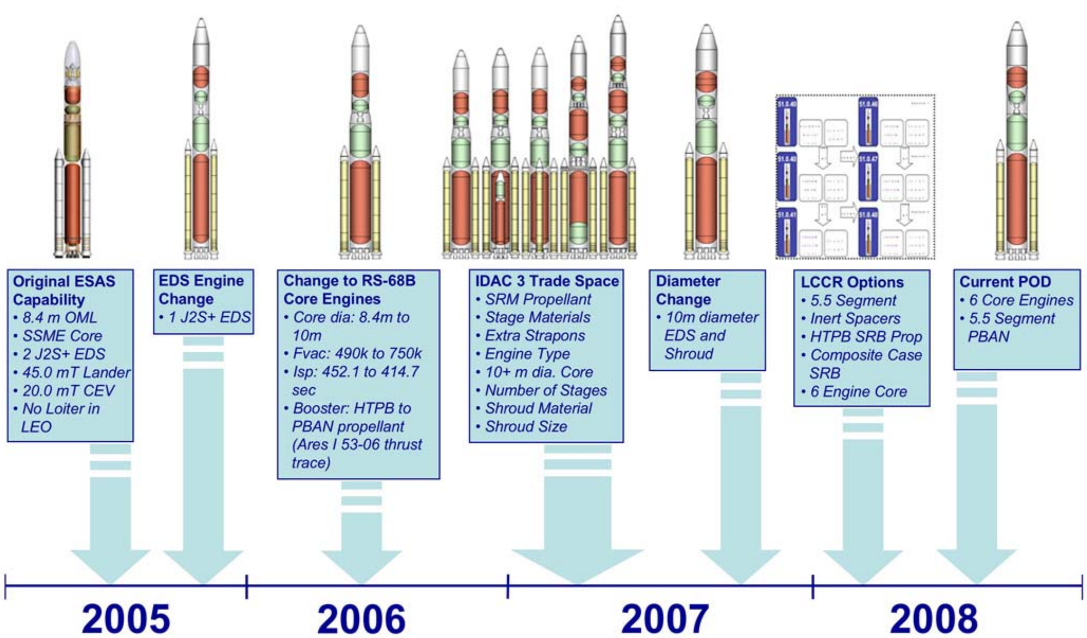

Figure 9. Ares V Concept Evolution from ESAS to LCCR.

III. Early Trade Studies

NASA studied hundreds of commercial, government, and concept launch vehicle architecture systems prior to 2005, culminating in the release of the ESAS final report. In a trade tree pruning exercise, the ESAS team evaluated non-assisted vs. assisted takeoff, vertical vs. horizontal takeoff, in-flight propellant tanking vs. no tanking, rocket vs. rocket and air-breathing vs. air breathing propulsion, expendable vs. partially reusable vs. fully reusable systems, single vs. 2-stage vs. 3-stage concepts, and "clean-sheet" vs. derivative systems. Also traded were Evolved Expendable Launch Vehicle (EELV)-derived vehicles vs. both side-mount and in-line Space Shuttle-derived vehicles vs. "clean-sheet" launch vehicle architectures. Figures of Merit (FOMs) used in the studies – cost, reliability, human safety, programmatic risk, mission performance, and schedule – 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. The Shuttle-derived approach allowed NASA to leverage significant existing ground infrastructure investments and personnel with significant human spaceflight experience. Also, the Shuttle-derived approach was found to be the most affordable, safest, and most reliable, both by leveraging proven human-rated vehicles and infrastructure elements and by using common elements across the architecture.

The ESAS-recommended Ares V POD, designated Concept 27.3, included two 5-segment, steel case SRBs with Hydroxyl-Terminated Polybutadiene (HTPB) propellant, which has a higher specific impulse (I_{sp}), density, and better mechanical properties than the Polybutadiene Acrylonitrile (PBAN) fueled Space Shuttle SRB. It had an 8.4-m (27.5-foot (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 LOX/LH_2 J-2S+ engines. The J-2S+ was designed 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 structures and propellant tanks. That Ares V variant had a Gross Liftoff Weight (GLOW) of nearly 6.4 million pounds. It was based on a 45t lunar lander, a 20t crew exploration vehicle, and no loiter period in LEO.

Several key changes made shortly after the ESAS are typical of the integrated systems approach of the dual-launch architecture. The EDS was reduced from two J-2S+ engines to a single J-2S+, which had the double benefit of reducing structural loads on the Orion/Altair docking system, as well as increasing TLI payload performance. Subsequently, NASA simplified the architecture to reduce the number of new development programs. When Ares I propulsion changed from a 4-segment booster to a 5-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. The J-2X was able to replace the J-2S+ on the Ares V EDS.

With the Ares V Core Stage the only remaining element supporting RS-25 production, the decision was made to reexamine the engine decision. As a result, the RS-68B, a variant of the commercial engine flying on the Boeing Delta IV vehicle, was selected 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.

Because of the RS-68B's lower efficiency, the Core Stage was enlarged from 8.4 m (27.5 ft.) to 10 m (33 ft.) in diameter to hold the extra required propellants and 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, had a GLOW of 7.3 million pounds and was nearly 362 feet tall. It exceeded the payload performance of the RS-25 solution by approximately 4t to TLI and enhanced the commonality between the

Ares vehicles, improving both development and operational efficiencies.

That configuration evolved in a series of trade studies involving shroud diameter, direct lunar missions, crew launch vehicle and upper stage placed on the Ares V, and added gravity losses on TLI burns and Flight Performance Reserve (FPR) allocation changes. The resulting new POD was nearly 365 feet tall. It served as the reference vehicle for a Performance Enhancement Study 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 effect on payload of several optional changes that would be important to later trades, including: replacing steel structures with composites, adding a sixth core engine and propellant, adding a pair of SRBs, adding a pair of Delta IV strap-on boosters, and adding an S-II-class second stage.

While those options increased payload, the study also concluded that some options carried penalties in other areas. Composite propellant tanks had 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 400 feet tall led to prohibitive KSC facility costs.

The Performance Enhancement Study then provided several changes that became the starting point for the 51-series of concept trades, which would then serve as the basis of the LCCR trade space formally assessed in June 2008.

Common features of all the 51-series configurations include a 10-m (33-ft.) diameter outer mold line (OML), composite materials for the payload shroud and all dry structures, and metallic (Aluminum-Lithium (Al-Li)) propellant tanks for the EDS and Core Stage. The 51-series vehicles reflect numerous changes to the ground rules and assumptions that shaped the earlier POD. Among those changes were:

- 14-day to 4-day loiter period
- 120-nmi to 130-nmi injection orbit
- 8.4-m to 10-m EDS diameter
- 8.4-m to 10-m 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 51.00.39 concept selected as the entry POD for LCCR was characterized by its 10-m standard Core Stage with 5 RS-68B engines with 2 5-segment steel-case, PBAN-propellant, reusable SRBs. Its TLI payload capability in conjunction with Ares I was 63.6t (140,2214 lbs). An expanded view is shown in Figure 10.

A stochastic analysis of 51.00.39 showed a reasonable conservatism in the performance estimate before system requirements review and system design review (SRR/SDR). The analysis showed that the 51.00.39 developed under the input conditions selected would have a TLI payload of 63.6 t under most of the design simulations performed.

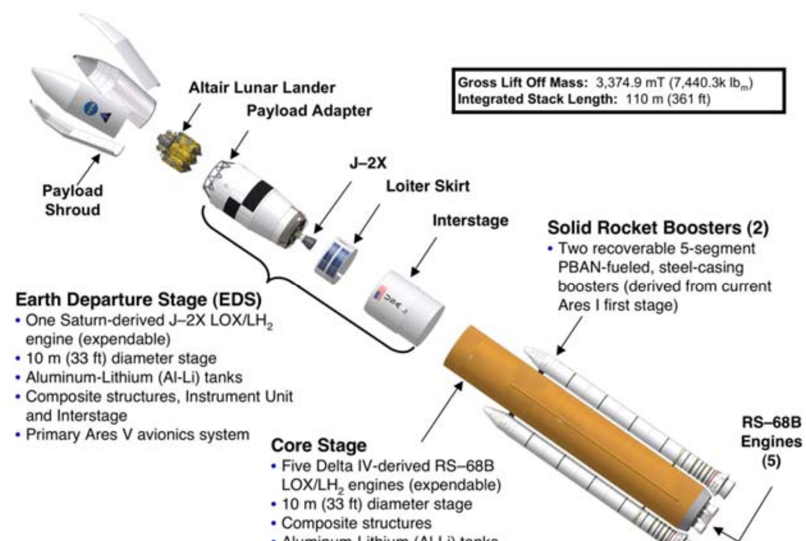

Figure 10. Expanded View of 51.00.39 Concept Vehicle – Entry POD for LCCR Trades.

IV. LCCR

The LCCR defined a POD transportation architecture for the Constellation Lunar Capability which includes the capability to perform short duration lunar surface crewed missions and enable establishment of a lunar outpost. The focus of the Ares V design team for the LCCR was to determine the driving requirements with appropriate performance margins and establish a POD vehicle configuration. The LCCR Trade Space represented a matrix of six optional configurations trading two Core Stage options mixed with three booster options. The Core options were the standard Core Stage with 5 RS-68 engines or a lengthened Core with an additional sixth engine. The booster options were the standard 5-segment steel case reusable booster with PBAN propellant, a 5-segment booster with a composite case expendable booster using more energetic HTPB propellant, or a 5.5-segment steel case, reusable booster using PBAN. The LCCR Trade Space is illustrated in Figure 11.

As a result of the LCCR, the previous POD, 51.00.39, was replaced with the new recommended POD, 51.00.48. It measures 116 m tall with a gross lift-off mass (GLOM) of 3,704.5 t (8.1 million lb). Its first stage will generate 11 million pounds of sea-level liftoff thrust. It will be capable of launching 187.7t (413,800 lb) to low Earth orbit (LEO), 55.6t (138,500 lb) direct to the Moon, or 71.1t (156,700 lb) in its dual-launch architecture role with Ares I.

By comparison, the Apollo-era Saturn V was 111m (364 ft) tall, with a GLOM of 2,948.4 t (96.5 million lb), and could carry 44.9t (99,000 pounds) to TLI or 118.8 t (262,000 pounds) to LEO. Effectively, in conjunction with Ares I, Ares V can launch 58 percent more payload to TLI than the Saturn V.

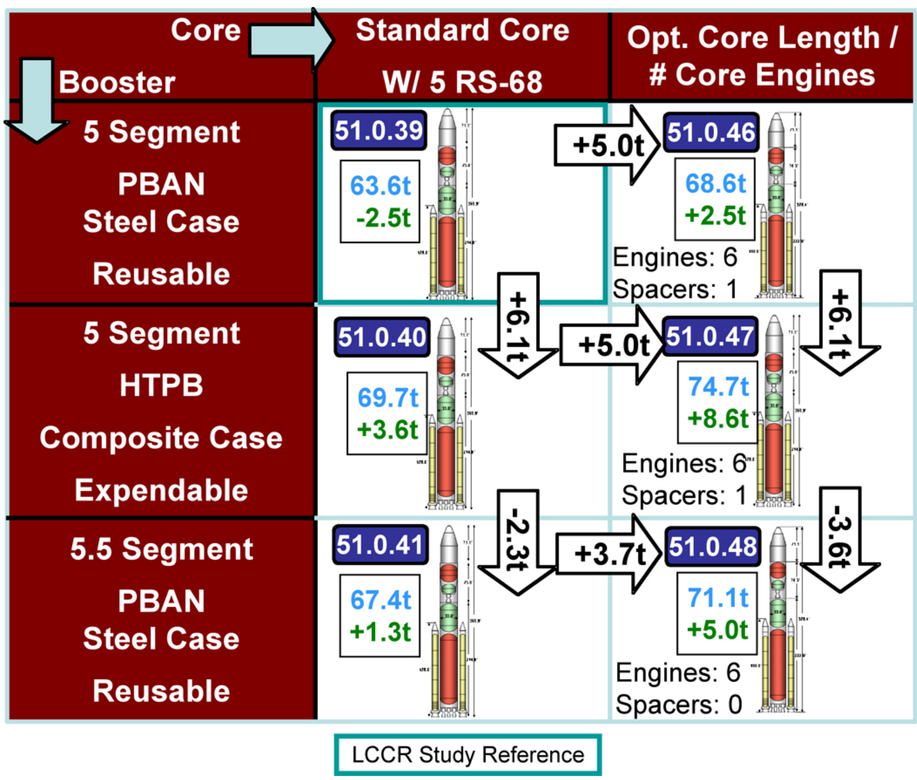

Figure 11. LCCR Tradespace highlighting the 51.00.39 reference for the trades.

The first stage propulsion of the 51.00.48 concept, shown in Figure 12, consists of a Core Stage powered by six commercial liquid hydrogen/liquid oxygen (LH_2/LOX) RS-68 engines, flanked by two 5.5-segment solid rocket boosters (SRBs) based on the 5-segment Ares I First Stage. The boosters use the same Polybutadiene Acrylonitrile (PBAN) propellant as the Ares I and Space Shuttle. Atop the Core Stage is the EDS, powered by a single J-2X upper stage engine based on the Ares I upper stage engine. The EDS carries a payload adapter and the Altair lander beneath a segmented payload shroud that will be the largest ever flown.

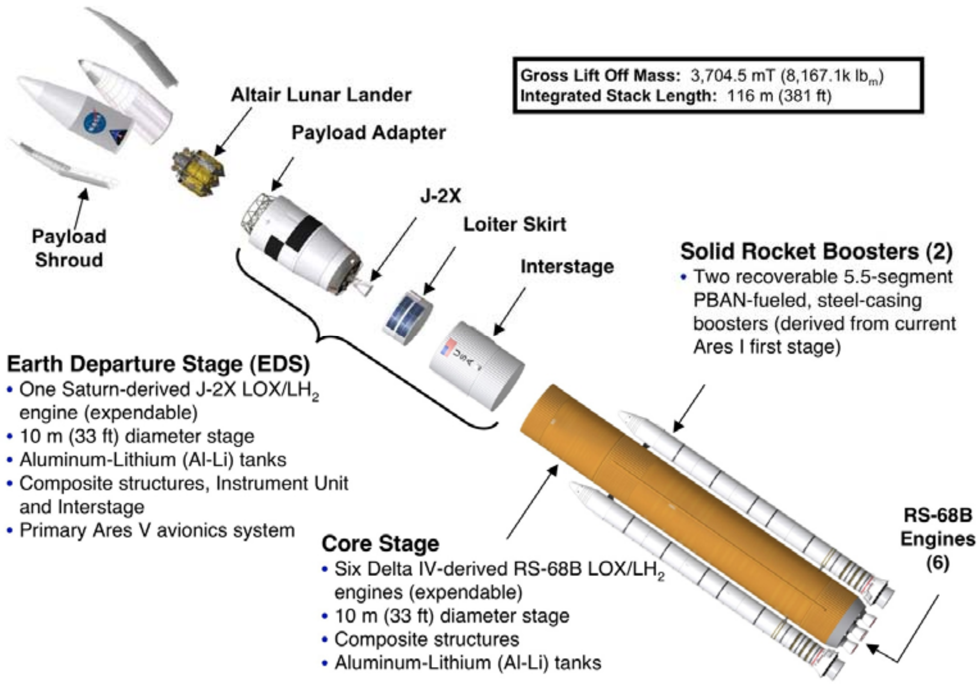

Figure 12. Expanded View of 51.00.48 Concept Vehicle – approved by LCCR

Constellation also approved an Ares Projects recommendation to retain concept 51.00.47 for further study of the benefits and risks associated. That version basically trades the 5.5-segment steel case PBAN reusable booster for a 5-segment composite case HTPB expendable booster.

Concurrent with the LCCR, an Ares V Concept Validation Study was initiated to provide a more in-depth and detailed Ares V design to validate the preliminary conceptual designs that the Advanced Concepts Office provided to the Ares Projects. Trades and analyses will identify technical issues with the design and areas of performance risk. The study will provide data for the Marshall Space Flight Center Advanced Concepts Office to upgrade its performance and sizing tools and processes if necessary. The results of the study will be collected in an Ares V Launch Vehicle Databook that will provide the technical foundation for a new Ares V reference concept and identify areas for future study.

The results of the Concept Validation Study and the results of the LCCR will be incorporated into a Design Analysis Cycle (DAC) 0 POD. The Ares V DAC-0 will kick off in Spring 2009 to further refine the vehicle. Ares V continues to evaluate systems-level impacts such as test facilities and schedule, the concept of operations, technology trade options that require prioritization, and further technology enhancements.

V. Conclusion

Systems design begun in the formative stages of NASA exploration architecture studies will provide the best possibility of meeting national goals and customer requirements within the available funding and timeframe desired. The design of the Ares V has evolved prudently from the ESAS baseline, making maximum use of existing human-rated systems and infrastructure. Hardware commonality between the Ares V and Ares I will minimize development and operations cost. Operability, reliability and safety are considered key inputs into the systems design process. By using a rigorous systems design process, Ares V expects to arrive at a System Requirements Review in 2011 with a design sufficiently mature to turn over to industry for proposals.

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International Astronautical Congress

September 29 - October 3, 2008

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Marshall Space Flight Center, NASA

Ares Projects Overview

- Deliver crew and cargo for missions to International Space Station (ISS), the Moon and beyond
- Continuing progress toward design, component testing, and early flight testing
- **Ares I Crew Launch Vehicle**
  - Carries 6 crew to ISS, 4 to Moon
  - First flight test scheduled in 2009
  - Initial Operational Capability in 2015
- **Ares V Cargo Launch Vehicle**
  - Launches Earth Departure Stage (EDS), Altair and Orion to Low Earth Orbit for lunar missions
  - Largest launch vehicle ever designed
  - Ongoing concept design work leading into detailed development work starting in 2011
  - First flight test planned in 2018

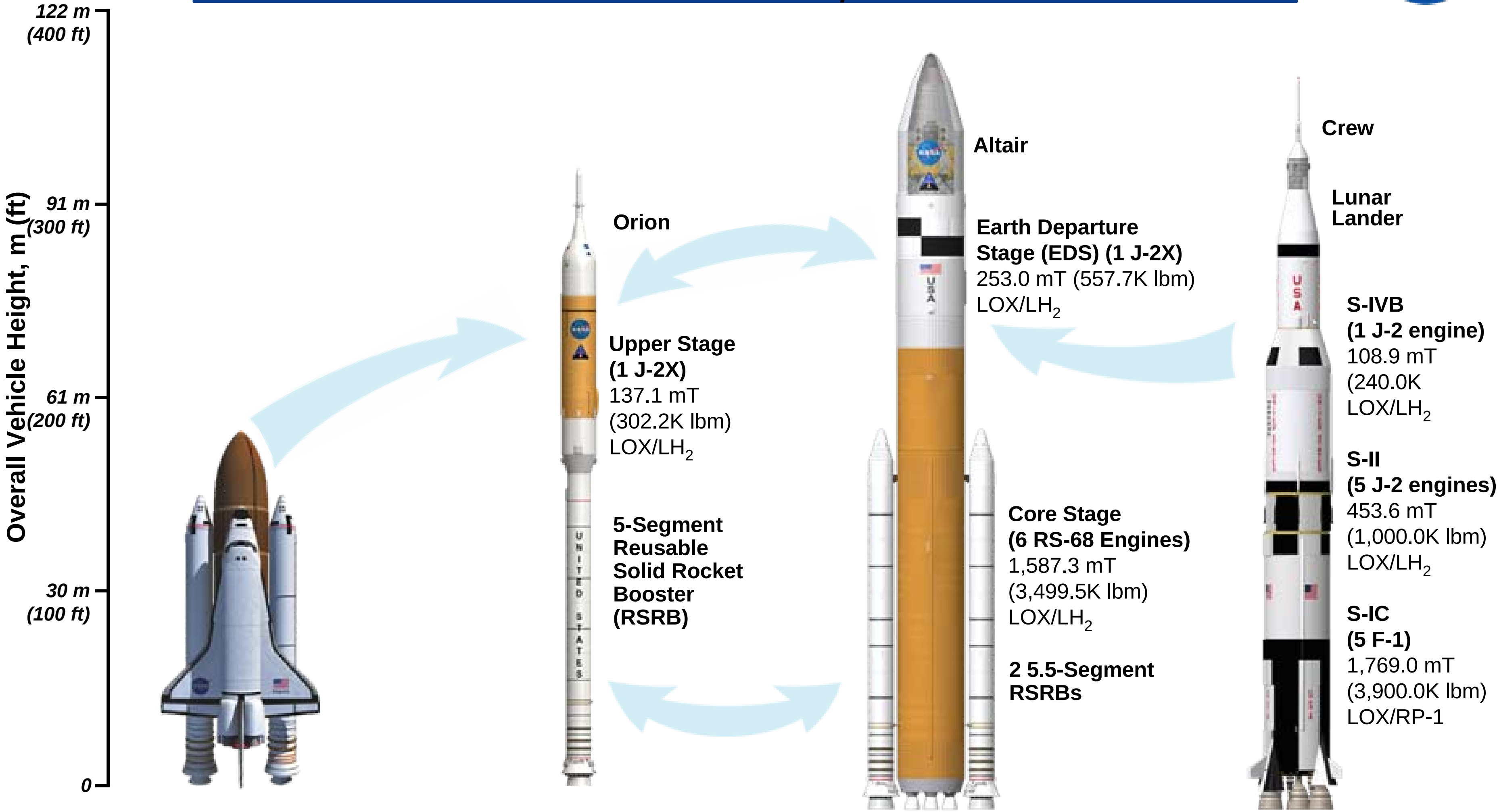
Ares V Cargo Launch Vehicle

Heavy Lift for Science and Exploration

- **Key transportation system for exploration beyond Low Earth Orbit**
  - Offers unique payload capabilities opening new doors to human exploration on the Moon and beyond
  - Designed for routine crew and cargo transportation to the Moon
    - **EDS + Altair to LEO**
    - **EDS + Altair + Orion to TLI**
  - Considered national asset creating new opportunities for science, national security and space business
  - Capable of transporting more than 71 metric tons to the Moon
  - Focal point for design and development located at MSFC with support across the Agency

Building on a Foundation of Proven Technologies

Launch Vehicle Comparisons



Space Shuttle

Height: 56.1 m (184.2 ft)
Gross Liftoff Mass:
2,041.1 mT (4,500.0K lbm)
Payload Capability:
25.0 mT (55.1K lbm) to Low Earth Orbit (LEO)

Ares I

Height: 99.1 m (325.0 ft)
Gross Liftoff Mass:
927.1 mT (2,044.0K lbm)
Payload Capability:
25.5 mT (56.2K lbm) to LEO

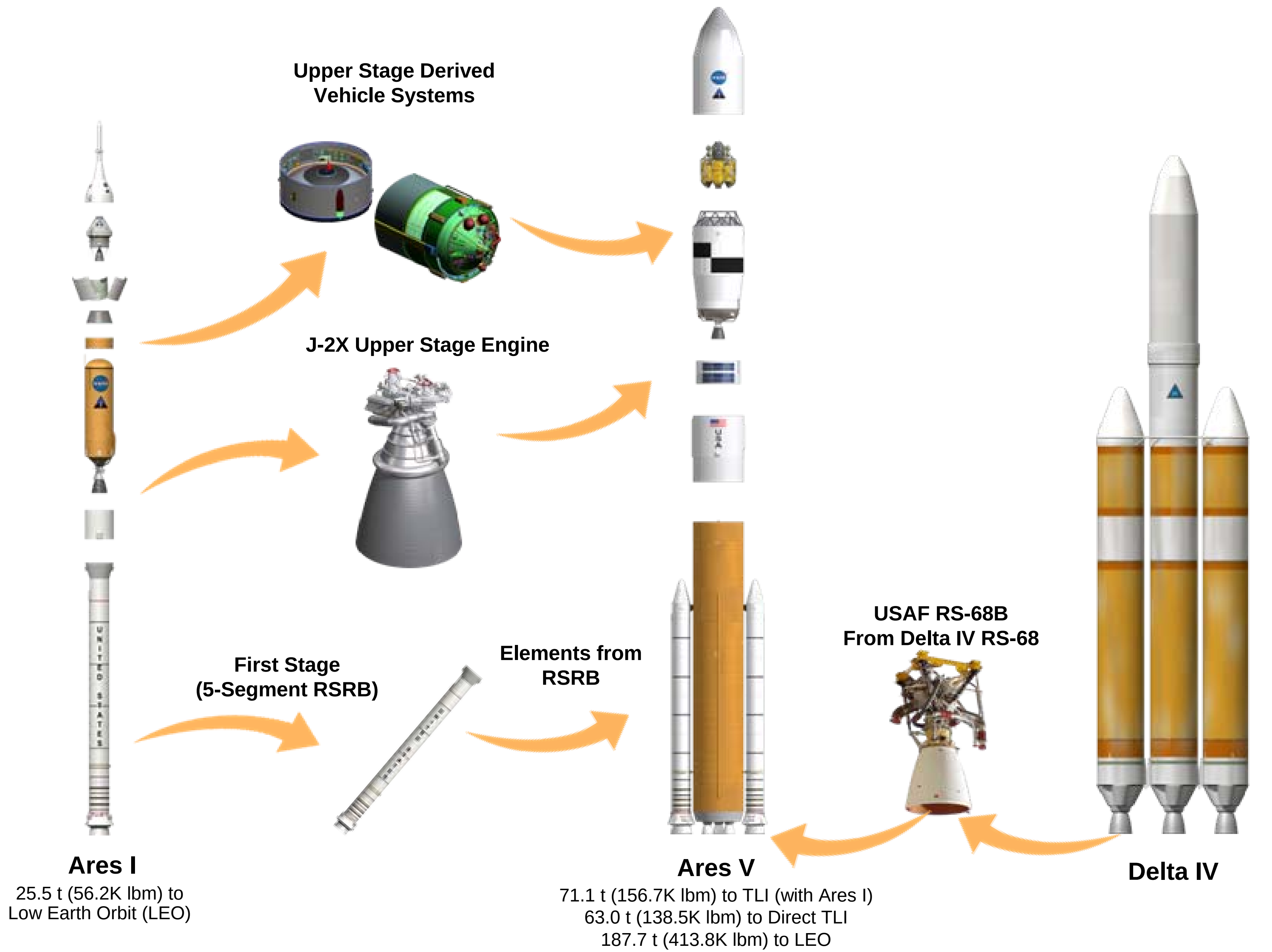
Ares V

Height: 116.2 m (381.1 ft)
Gross Liftoff Mass:
3,704.5 mT (8,167.1K lbm)
Payload Capability:
71.1 mT (156.7K lbm) to TLI (with Ares I)
62.8 mT (138.5K lbm) to Direct TLI
~187.7 mT (413.8K lbm) to LEO

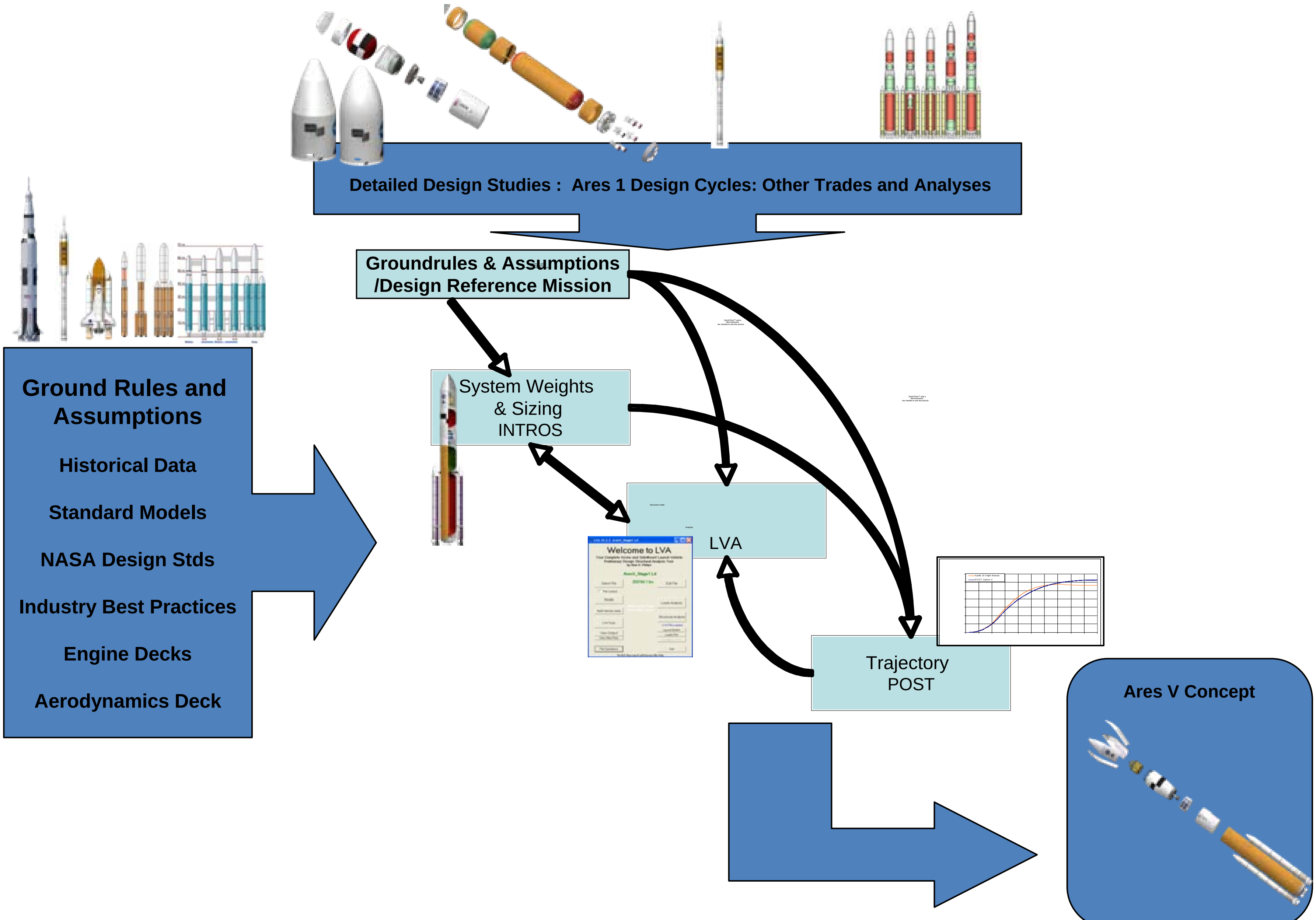
Saturn V

Height: 110.9 m (364 ft)
Gross Liftoff Mass:
2,948.4 mT (6,500K lbm)
Payload Capability:
44.9 mT (99K kbm) to TLI
118.8 mT (262K lbm) to LEO

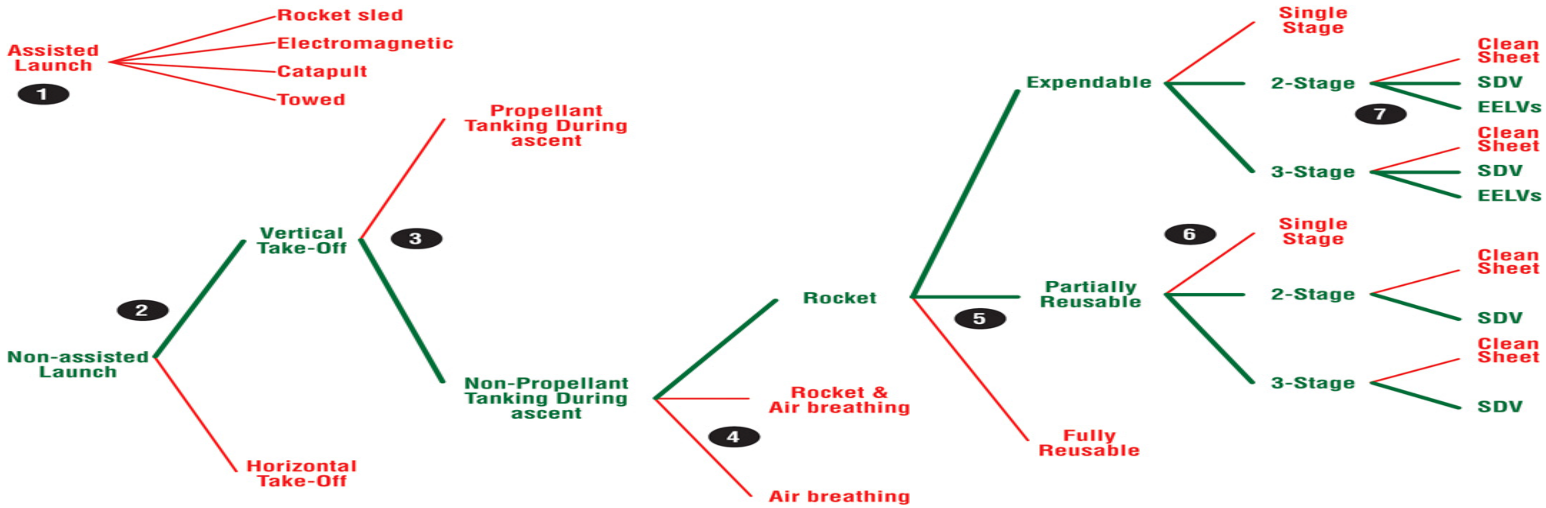
Ares V Element Heritage



Ares V Design Process

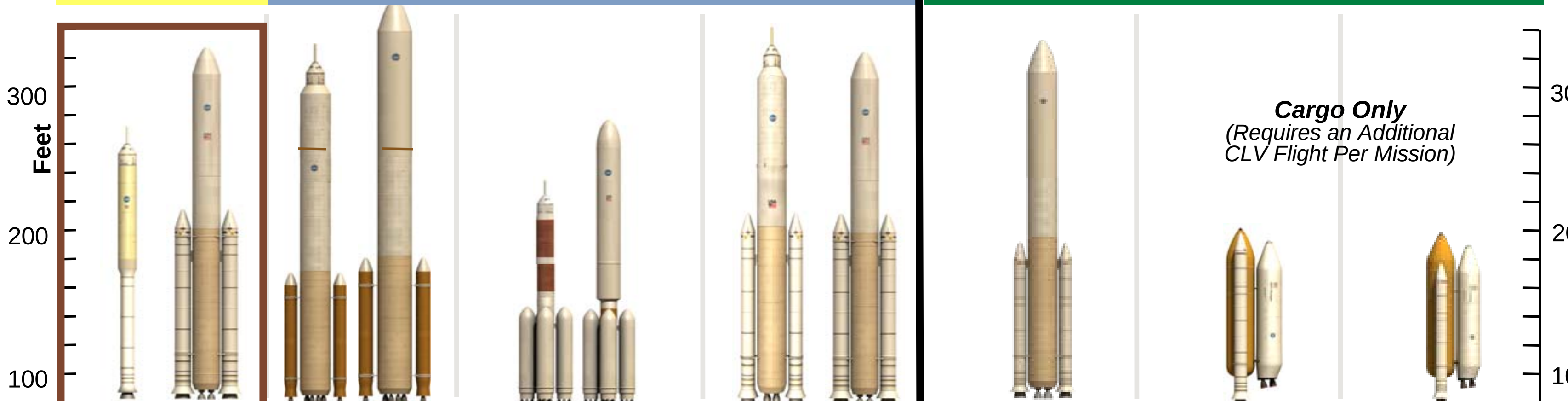


ESAS Integrated Trade Tree Pruning Rationale



1. *Non-assisted versus Assisted Takeoff*: **Assisted launch systems (e.g., rocket sled, electromagnetic sled, towed) on the scale necessary to meet the payload lift requirements are beyond the state-of the-art for near-term application. Therefore, Non-assisted Takeoff was chosen.**
2. *Vertical versus Horizontal Takeoff*: **Current horizontal takeoff vehicles and infrastructures are not capable of accommodating the gross takeoff weights of concepts needed to meet the payload lift requirements. Therefore, Vertical Takeoff was chosen.**
3. *No Propellant Tanking versus Propellant Tanking During Ascent*: **Propellant tanking during vertical takeoff is precluded due to the short period of time spent in the atmosphere (1) to collect propellant or (2) to transfer propellant from another vehicle. Therefore, No Propellant Tanking was chosen.**
4. *Rocket versus Rocket and Air Breathing versus Air Breathing*: **Air breathing and combined cycle (i.e., rocket and air breathing) propulsion systems are beyond the state-of-the-art for near-term application and likely cannot meet the lift requirements. Therefore, Rocket was chosen.**
5. *Expendable versus Partially Reusable versus Fully Reusable*: **Fully reusable systems are not cost-effective for the low projected flight rates and large payloads. Near-term budget availability and the desire for a rapid development preclude fully reusable systems. Therefore, Expendable or Partially Reusable was chosen.**
6. *Single-stage versus 2-Stage versus 3-Stage*: **Single-stage concepts on the scale necessary to meet the payload lift requirements are beyond the state-of-the-art for near-term application. Therefore, 2-Stage or 3-Stage was chosen.**
7. *Clean-sheet versus Derivatives of Current Systems*: **Near-term budget availability and the desire for a rapid development preclude clean-sheet systems. Therefore, Derivatives of Current Systems were chosen.**

Lunar Crew/Cargo Launch Comparison



	"1.5" Launch	2 Launch Solutions			3+ Launch Solutions		
	5 Segment RSRB In-Line with 5 SSME Core - Cargo	Atlas Phase X (8m Core)	Atlas Phase 3A (5.4m Core)	5 Segment RSRB In-Line with 4 SSME Core	4 Segment RSRB In-Line with 3 SSME Core	5 Segment RSRB Sidemount with 3 SSME	4 Segment RSRB Sidemount with 3 SSME
Payload to 28.5	106 t (125 t w/ upperstage)	95 t	94 t	97 t	74 t	80 t	67 t
Lunar LV DDT&E*	1.00	1.29	0.59	0.96	0.73	0.80	0.75
CLV+Lunar Crew/Cargo DDT&E (family op)*	1.00 (4 Seg RSRB w/1 SSME)	1.26 (Atlas V)	1.02 (Phase 2)	.98 (4 Seg RSRB w/1 SSME)	.83 (4 Seg RSRB w/1 SSME)	1.03 (5 Seg RSRB w/J2S-RL85)	.85 (4 Seg RSRB w/1 SSME)
Lunar LV Facility DDTE	1.00	1.33	2.25	1.00	• All cost estimates include reserves (20% for DDT&E, 10% for Operations, Government oversight/full cost; Average cost/flight based on 6 launches per year ** Production costs are higher than in-line due to production of separate side-mount cargo carrier		
CLV+Lunar Facilities Cost	1.00	1.12	1.56	1.00			
Average Cost/Flight*	1.00	1.08	1.19	0.87	0.78	1.13**	1.13**
LOM – Cargo(mean)	1 in 124	1 in 71	1 in 88	1 in 133	1 in 176	1 in 172	1 in 173
LOC (mean)	N/A	1 in 536	1 in 612	1 in 915	1 in 1,170	N/A	N/A

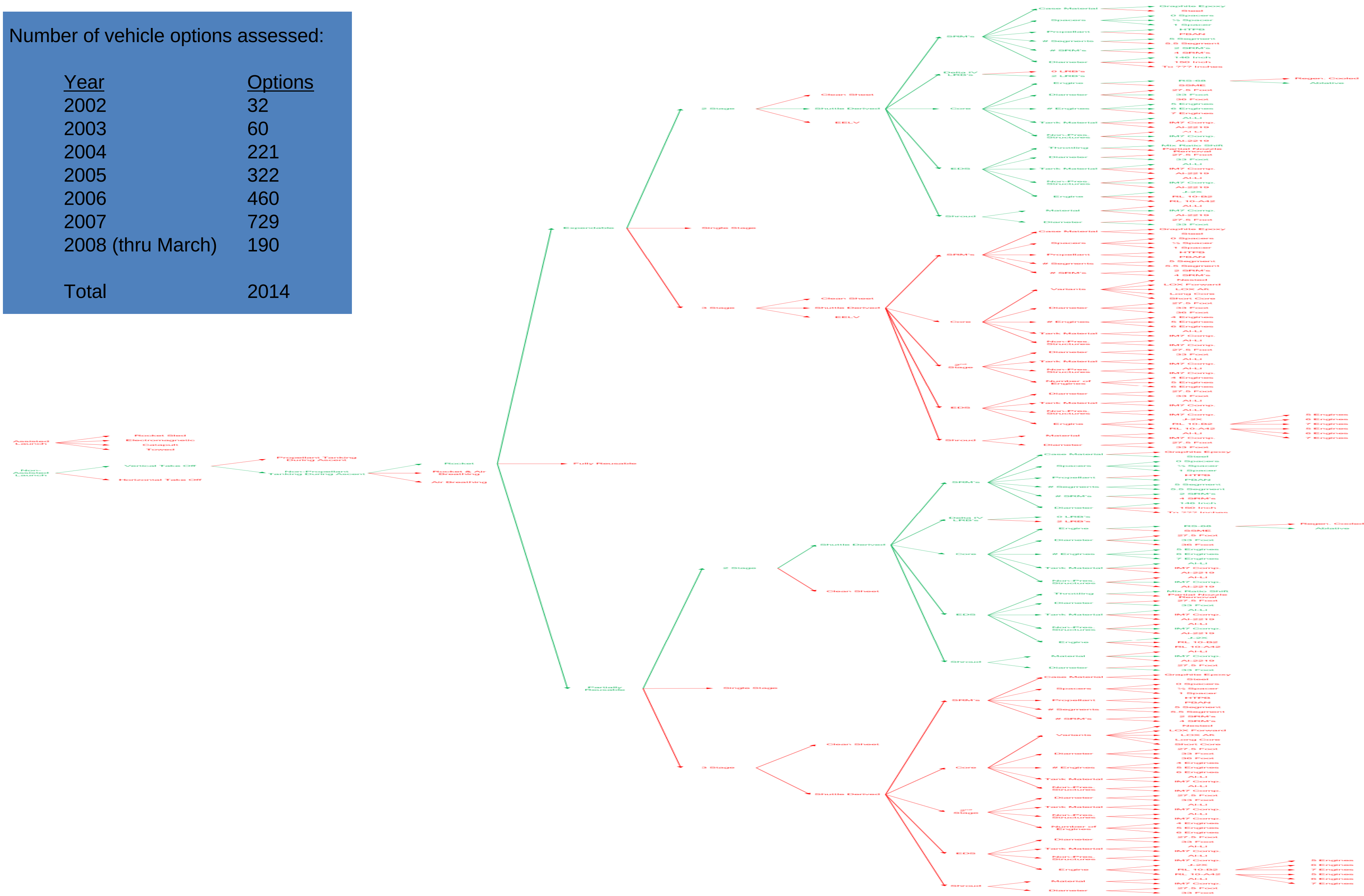
ESAS Final Report - Figure 6-96 Lunar Cargo Launch Comparison

Integrated Trade Tree

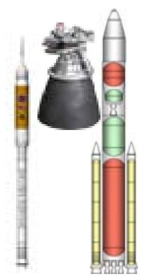
- ESAS to LCCR -

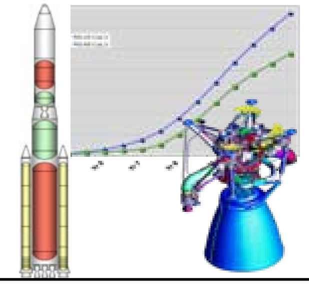
Number of vehicle options assessed:

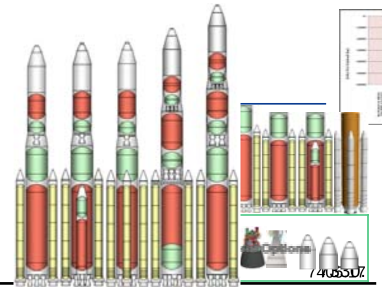
Year	Options
2002	32
2003	60
2004	221
2005	322
2006	460
2007	729
2008 (thru March)	190
Total	2014

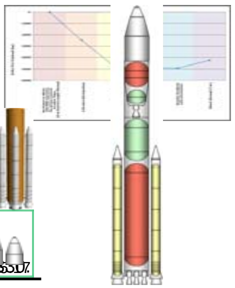


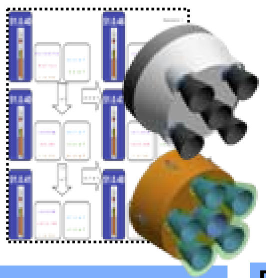
ESAS to LCCR Major Events

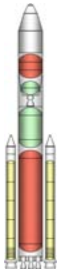












Original ESAS Capability

- *45.0 mT Lander*
- *20.0 mT CEV*
- *No Loiter in LEO*
- *8.4m OML*
- *5 SSMEs / 2J2S*

CY-06 Budget Trade to Increase

- **Ares I / Ares V Commonality**
- **Ares I : 5 Seg RSRB / J2-X instead of Air-Start SSME**
- **Ares V: 1 J2-X**

Detailed Cost Trade of SSME vs RS-68

- **~$4.25B Life Cycle Cost Savings for**
- **5 Engine Core**
- **Increased Commonality with Ares I Booster**
- **30-95 Day LEO Loiter Assessed**

IDAC 3 Trade Space

- **Lunar Architecture Team 1/2 (LAT) Studies**
- **Mission Delta V's increased**
- **Increase Margins From TLI Only to Earth through TLI**
- **Loiter Penalties for 30 Day Orbit Quantified**

EDS Diameter Change from 8.4m to 10m

- **Lunar Architecture Team 1/2 (LAT) Studies**
- **Lunar /Mars Systems Benefits**
- **Tank Assembly Tooling Commonality**

Incorporate Ares I Design Lessons Learned / Parameters

- **Core Engine / SRB Trades to Increase Design Margins**
- **Increase Subsystem Mass Growth Allowance (MGA)**

Recommended Option

- *6 Core Engines*
- *5.5 Segment PBAN*

Updated Capability

- 45.0t Lander
- 20.2t CEV
- ~6t Perf. Margin
- 4 Day LEO Loiter
- Ares I Common MGAs
- HTPB Decision End of FY09

220 Concepts Evaluated

320 Concepts Evaluated

730 Concepts Evaluated

460 Concepts Evaluated

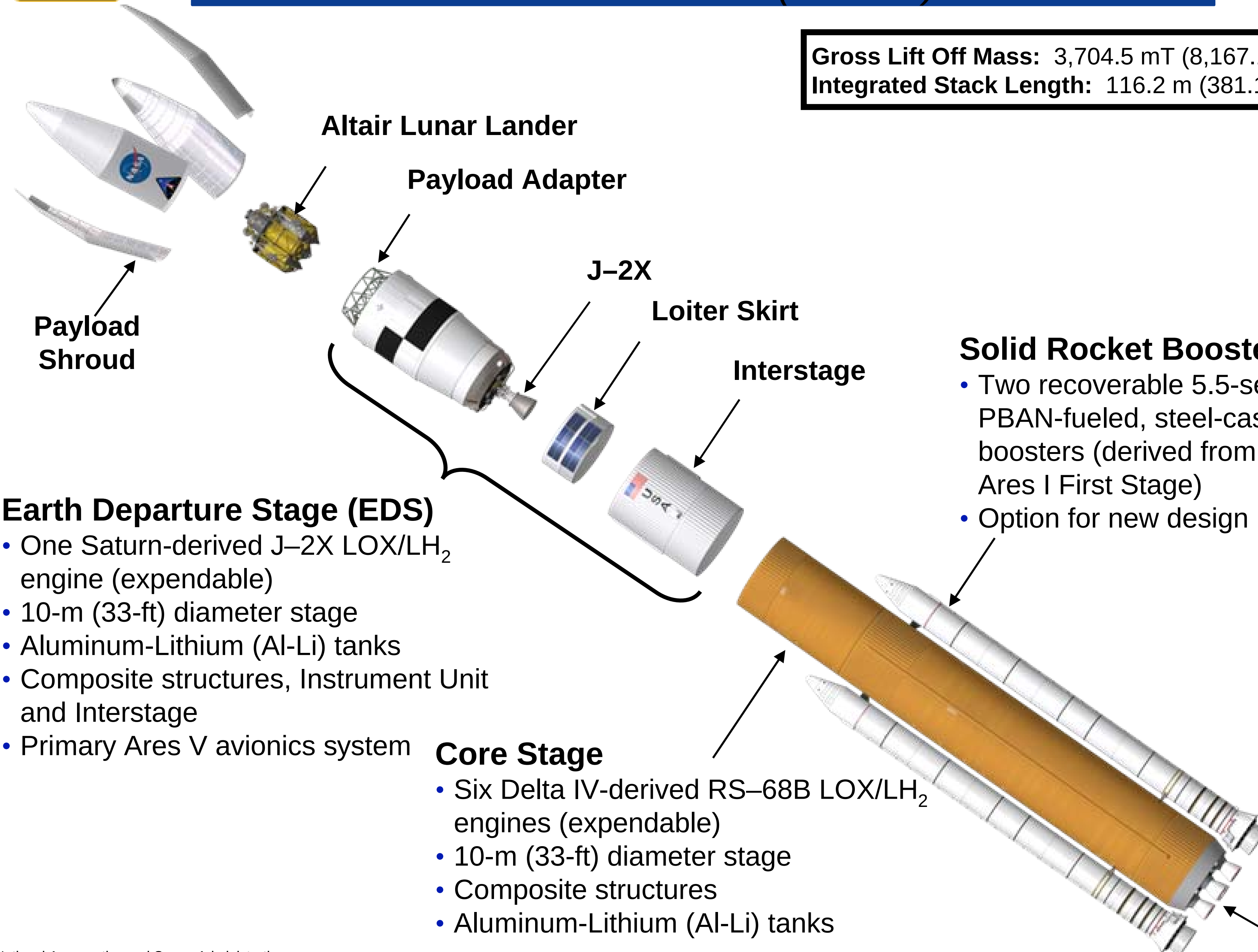
2005 | **2006** | **2007** | **2008**

ESAS Complete — **Ares I ATP** — **Orion ATP** — **Ares I SRR** — **Orion SRR** — **Ares I SDR** — **Ares V MCR**

Ares V Elements

New LCCR POD (51.0.48)

Gross Lift Off Mass: 3,704.5 mT (8,167.1k lbm)
Integrated Stack Length: 116.2 m (381.1 ft)



Solid Rocket Boosters (2)

- Two recoverable 5.5-segment PBAN-fueled, steel-case boosters (derived from current Ares I First Stage)
- Option for new design

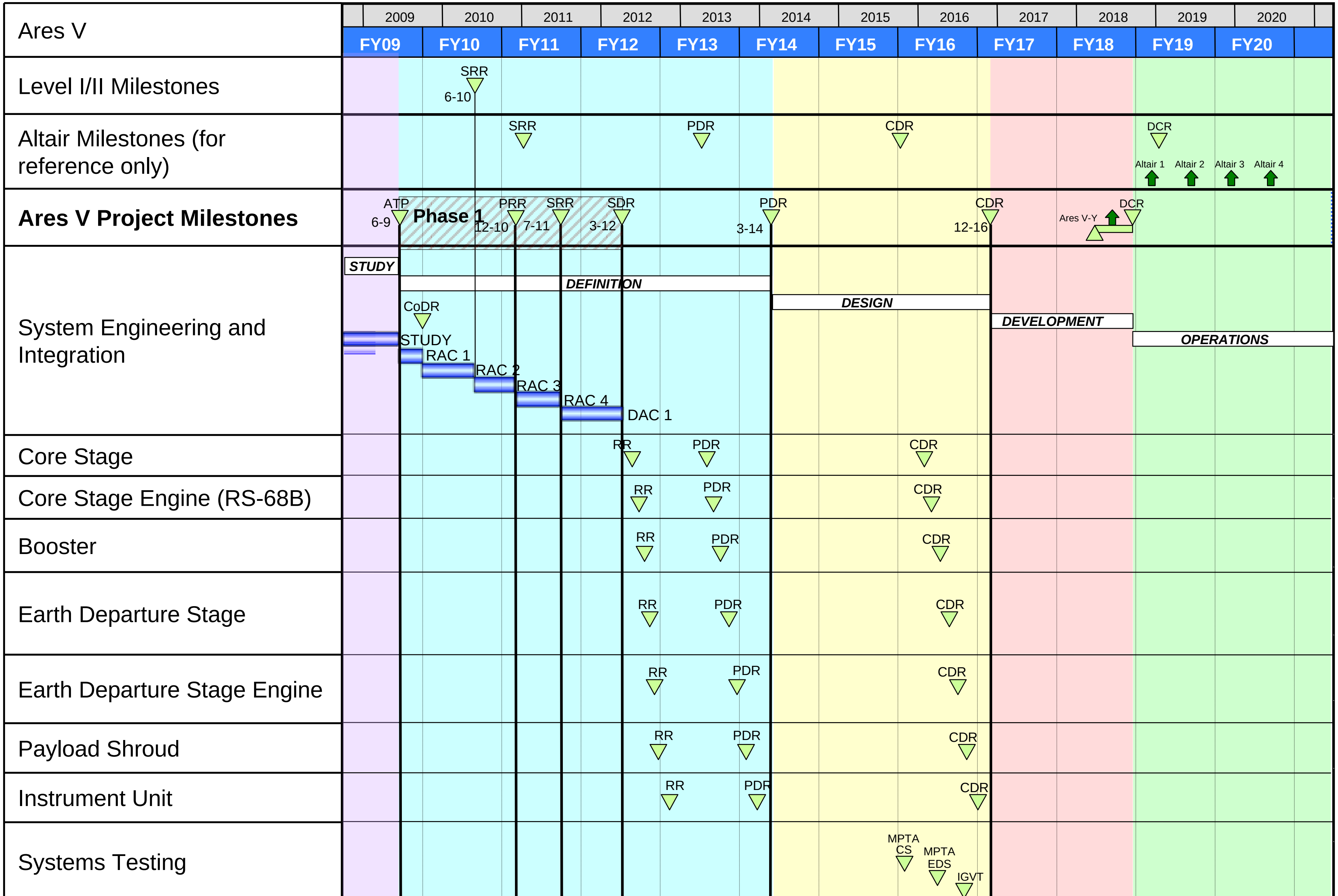
Earth Departure Stage (EDS)

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

Core Stage

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

Ares V Summary Schedule



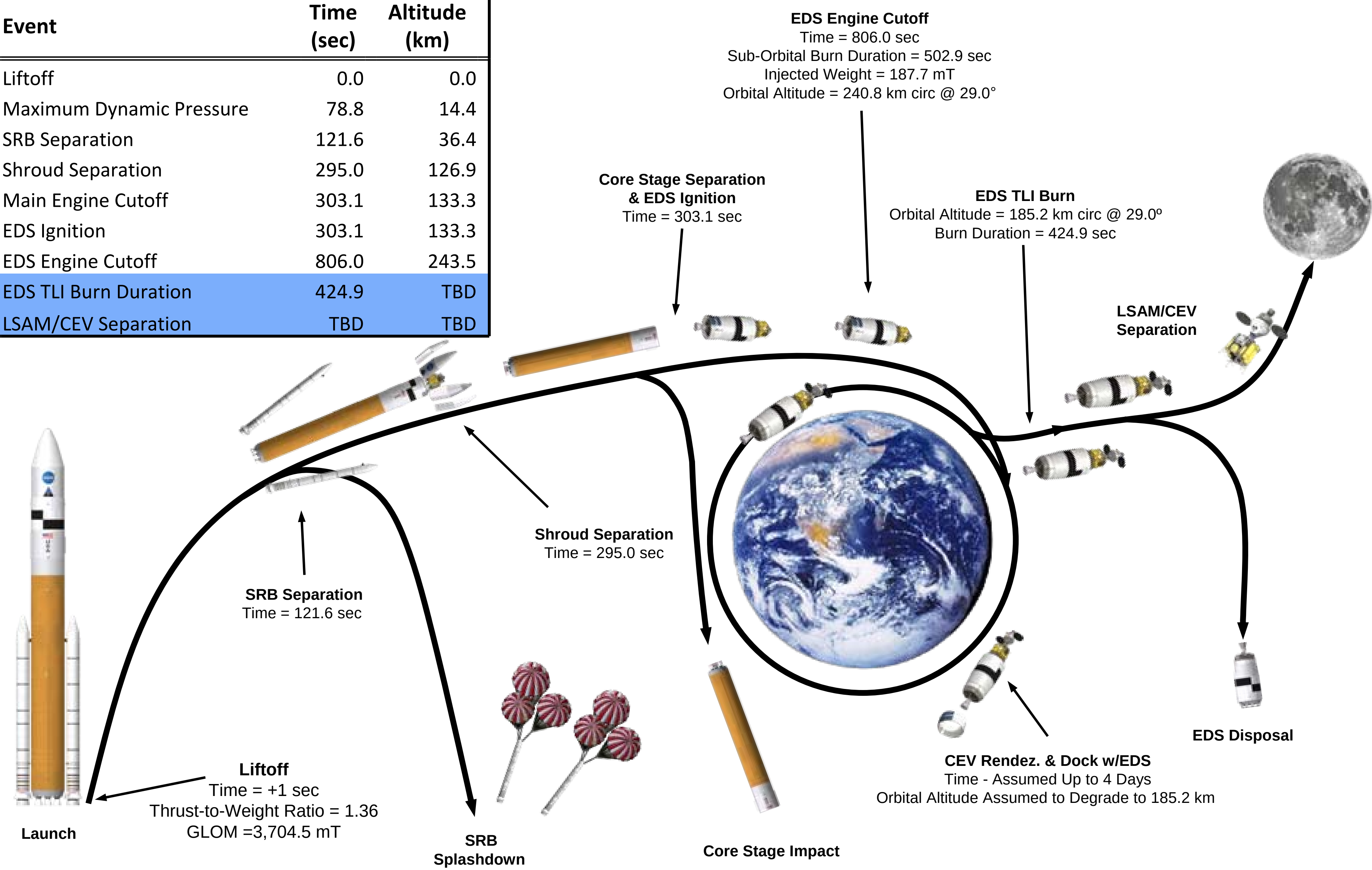
Key Schedule Milestones

- MCR — Summer 2008
- ATP — Summer 2009
- PRR — Winter 2010
- SRR — Summer 2011
- SDR — Spring 2012
- PDR — Spring 2014
- CDR — Winter 2016
- First Mission Flight — Fall 2018

Ares V Profile for 1.5 Launch DRM

51.00.48 Approved POD (Lunar Sortie)

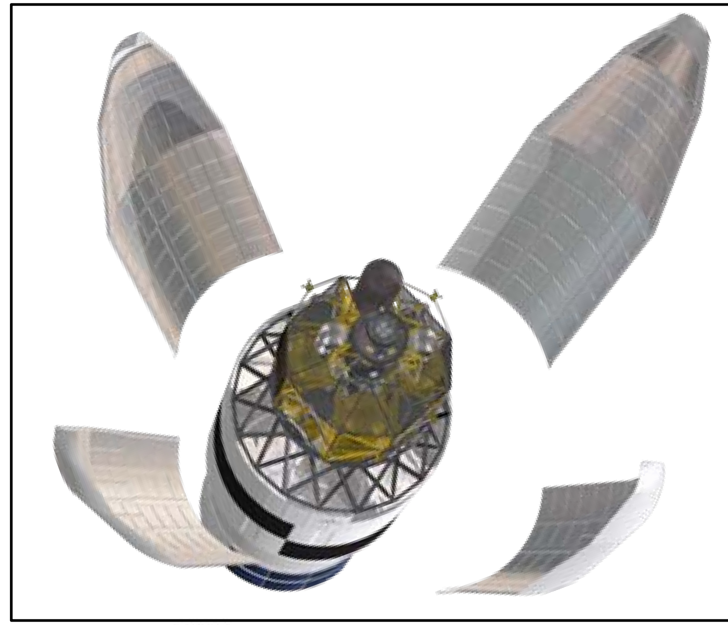
Event	Time (sec)	Altitude (km)
Liftoff	0.0	0.0
Maximum Dynamic Pressure	78.8	14.4
SRB Separation	121.6	36.4
Shroud Separation	295.0	126.9
Main Engine Cutoff	303.1	133.3
EDS Ignition	303.1	133.3
EDS Engine Cutoff	806.0	243.5
EDS TLI Burn Duration	424.9	TBD
LSAM/CEV Separation	TBD	TBD

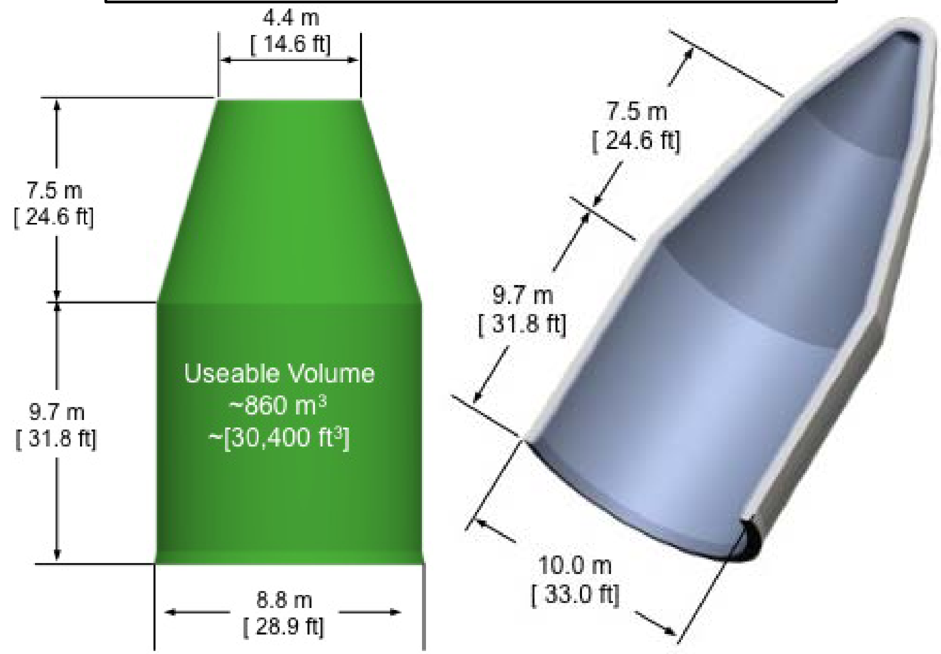


Payload Utilization

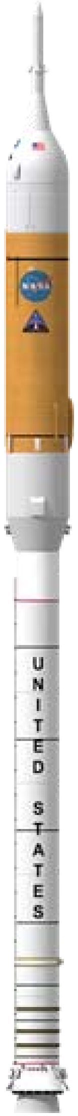
Ares V as a National Asset

- **Ares V offers the largest payload capability than all other existing launch vehicles**
  - Over 40% more lift capability than Saturn V
  - 3-5 times for volume than most other launch systems
- **These unique capabilities open new worlds and create unmatched opportunities**
  - Human exploration
  - Science
  - Space Business
- **Ares V is actively engaged with external organizations during this early concept phase to ensure its utilization for other missions**
  - National security
  - Astronomy and Solar System Science





Our Achievements



Programmatic Milestones

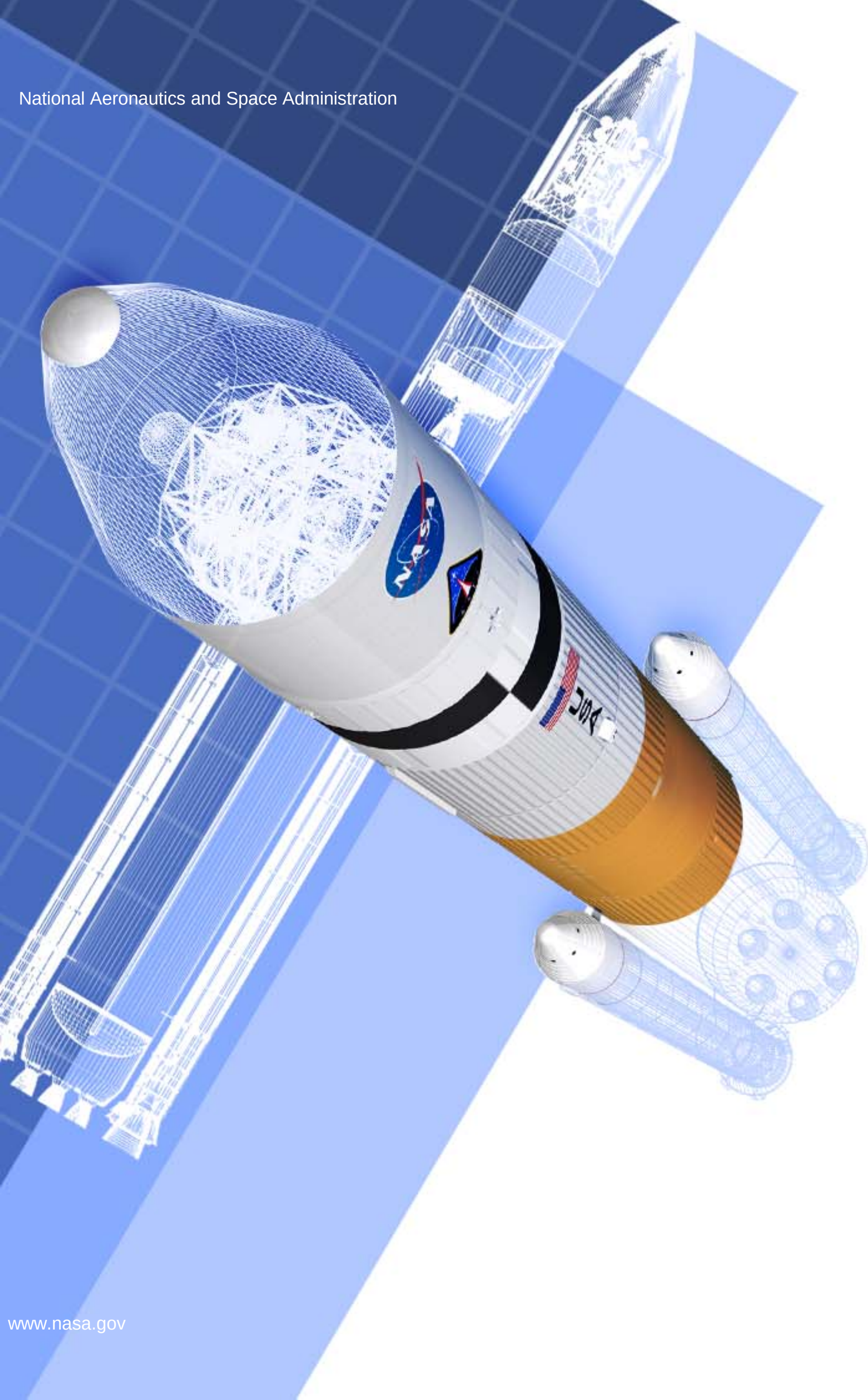
- Completed Ares I System Requirements Review (SRR) – Jan 2007
- Awarded contracts for Ares I First Stage, J-2X Engine, Upper Stage and Instrument Unit
- Completed Ares I System Definition Review (SDR) – Oct 2007
- Completed Ares V Mission Concept Review (MCR) – Jun 2008
- Completed Constellation Lunar Capability Concept Review (LCCR) – Jun 2008
- Completed Ares I-X Critical Design Review (CDR) – Jul 2008
- Released Ares V Request For Information (RFI) and evaluating responses – Aug 2008
- Completion of Ares I Preliminary Design Review (PDR) – Sep 2008

Technical Accomplishments

- Ares I Drogue Chute Drop Test – July 2008
- Ares I First Stage Separation and Re-entry Wind Tunnel Tests
- J-2X Injector and Power Pack Tests
- Ares I-X Roll Control System (RoCS) Module Cold Flow Test – September 2008
- Ares I-X Hardware Fabrication
- A-3 Test Stand Construction for J-2X Engine at Stennis Space Center
- MSFC Dynamic Test Stand 4550 Refurbishment for Ares I and Ares V Integrated Vehicle Ground Vibration Testing
- Established Ares V Design Concept Which Fully Supports the Constellation Architecture

Summary

- Key elements of Ares V are under development as a part of Ares I and the Air Force RS-68
- Ares V Point of Departure (POD) vehicle has ~ 40% more payload capability than Saturn V which closes the lunar architecture with 6 MT of margin to TLI
- Ares V design and development will begin in 2011
- Ares V completed its Mission Concept Review (MCR) in June of this year and is proceeding into Phase A
- Industry involvement in Ares V Phase I will support element definition to assure robust system level requirements leading to element prime contract awards in Phase II



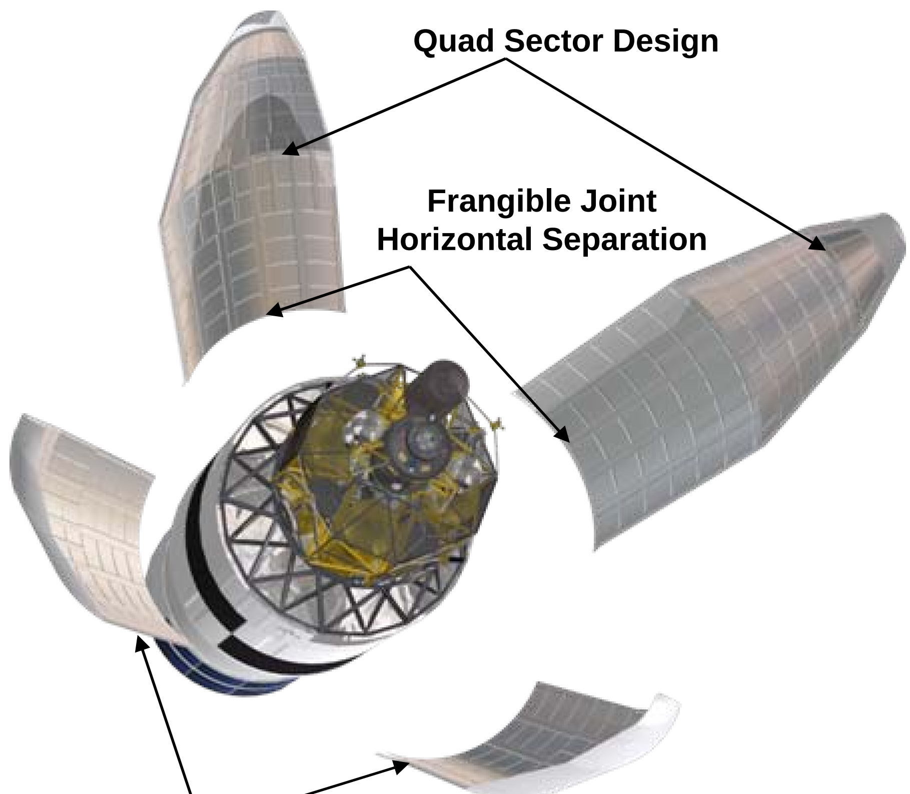
Backup

Payload Shroud Design Concept

Mass: 9.1 t (20.0k lbm)
POD Geometry: Biconic
Design: Quad sector
Barrel Diameter: 10 m (33 ft)
Barrel Length: 9.7 m (32 ft)
Total Length: 22 m (72 ft)

Point of Departure (Biconic) | **Leading Candidate (Ogive)**

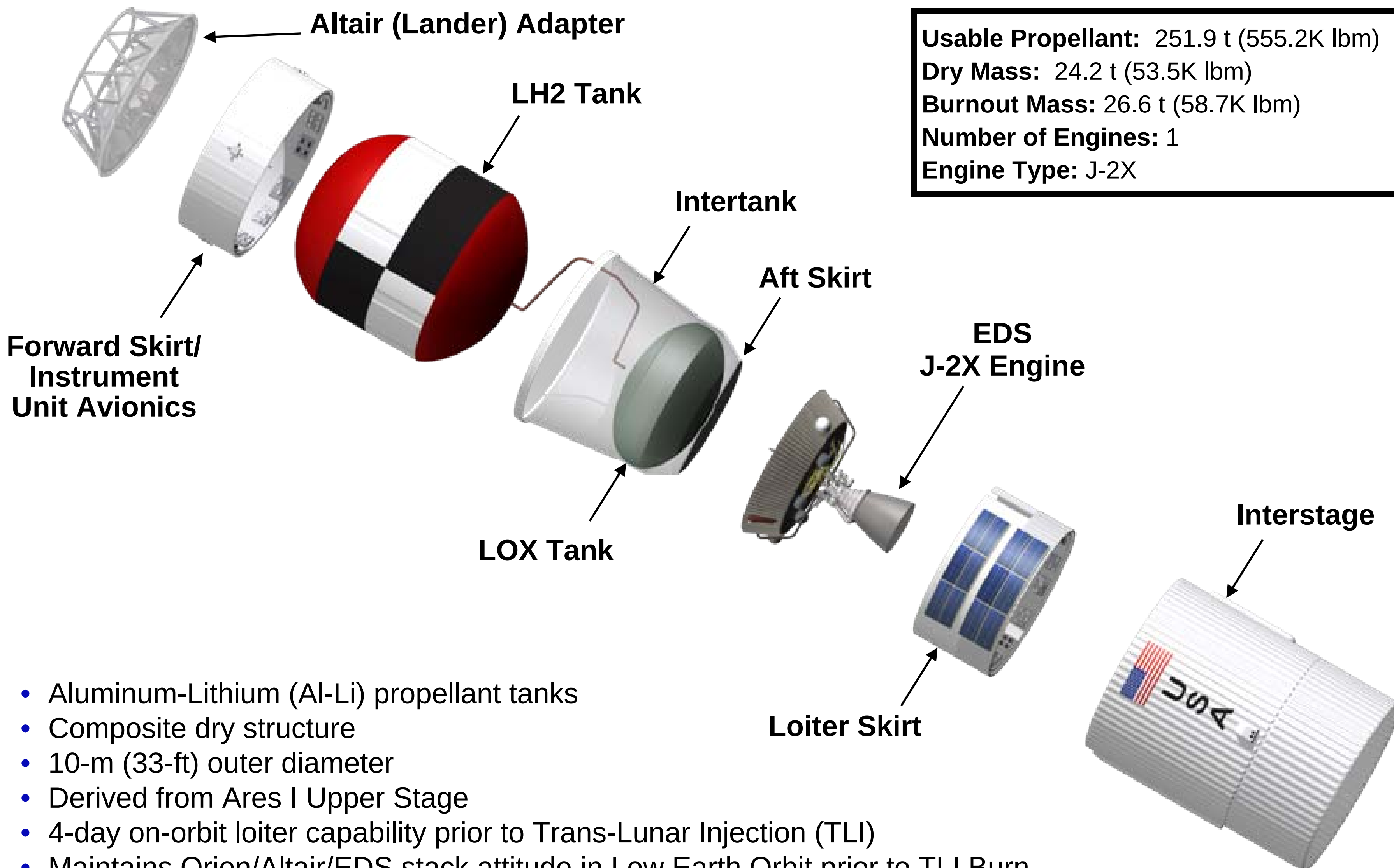
- Composite sandwich construction (Carbon-Epoxy face sheets, Al honeycomb core)
- Painted cork TPS bonded to outer face sheet with RTV
- Payload access ports for maintenance, payload consumables and environmental control (while on ground)



Earth Departure Stage Current Design Concept

Expanded View

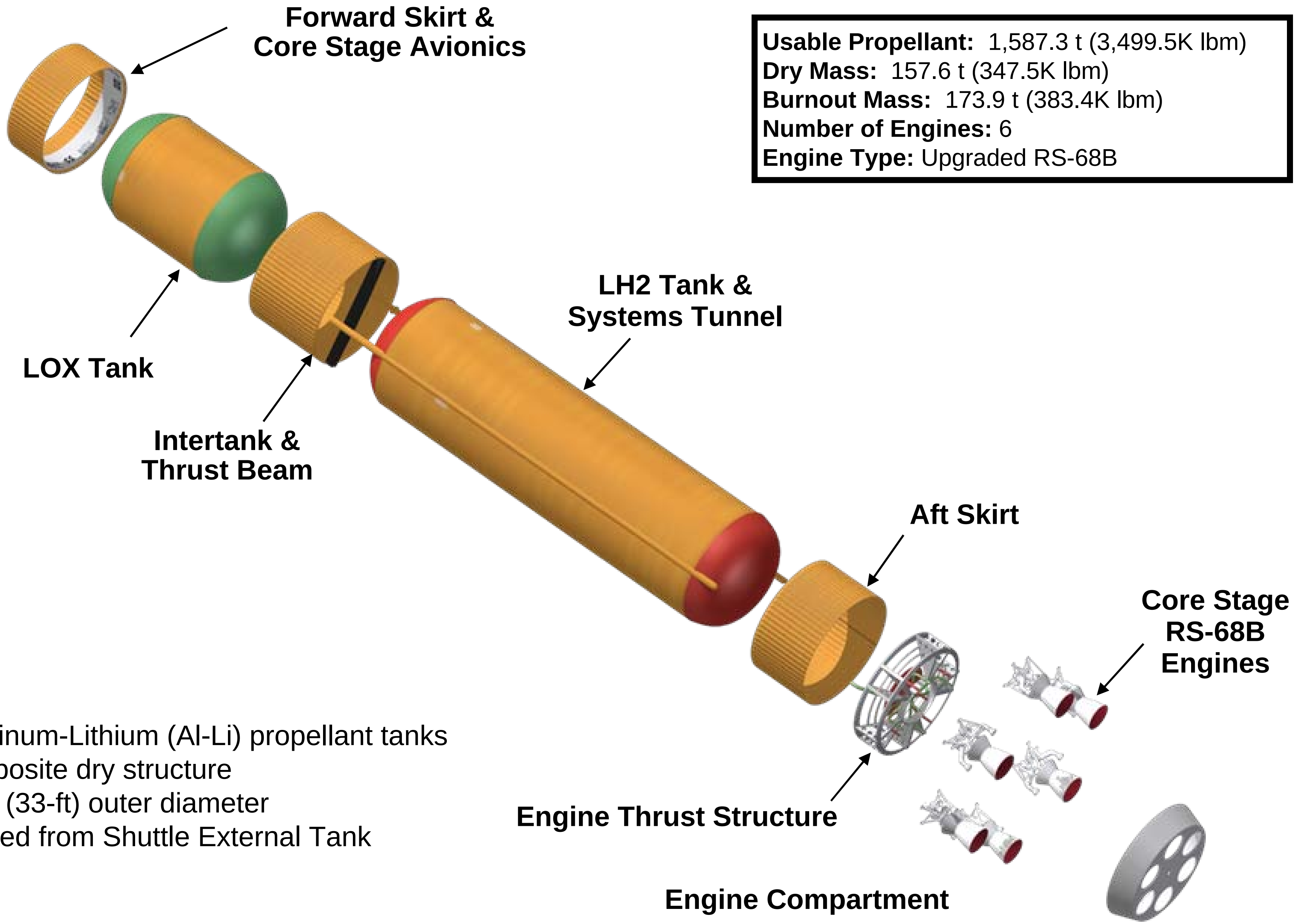
Usable Propellant: 251.9 t (555.2K lbm)
Dry Mass: 24.2 t (53.5K lbm)
Burnout Mass: 26.6 t (58.7K lbm)
Number of Engines: 1
Engine Type: J-2X



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

Core Stage Current Design Concept
- Expanded View -

Usable Propellant: 1,587.3 t (3,499.5K lbm)
Dry Mass: 157.6 t (347.5K lbm)
Burnout Mass: 173.9 t (383.4K lbm)
Number of Engines: 6
Engine Type: Upgraded RS-68B



- Aluminum-Lithium (Al-Li) propellant tanks
- Composite dry structure
- 10-m (33-ft) outer diameter
- Derived from Shuttle External Tank

Earth Departure Stage J-2X Engine

Turbomachinery
- Based on J–2S MK–29 design

Flexible Inlet Ducts
- Based on J–2 & J–2S ducts

Gas Generator
- Based on RS–68 design

Open-Loop Pneumatic Control
- Similar to J–2

Engine Controller
- Based directly on RS–68 design and software architecture

HIP-bonded MCC
- Based on RS–68 demonstrated technology

Regeneratively Cooled Nozzle Section
- Based on long history of RS–27 success

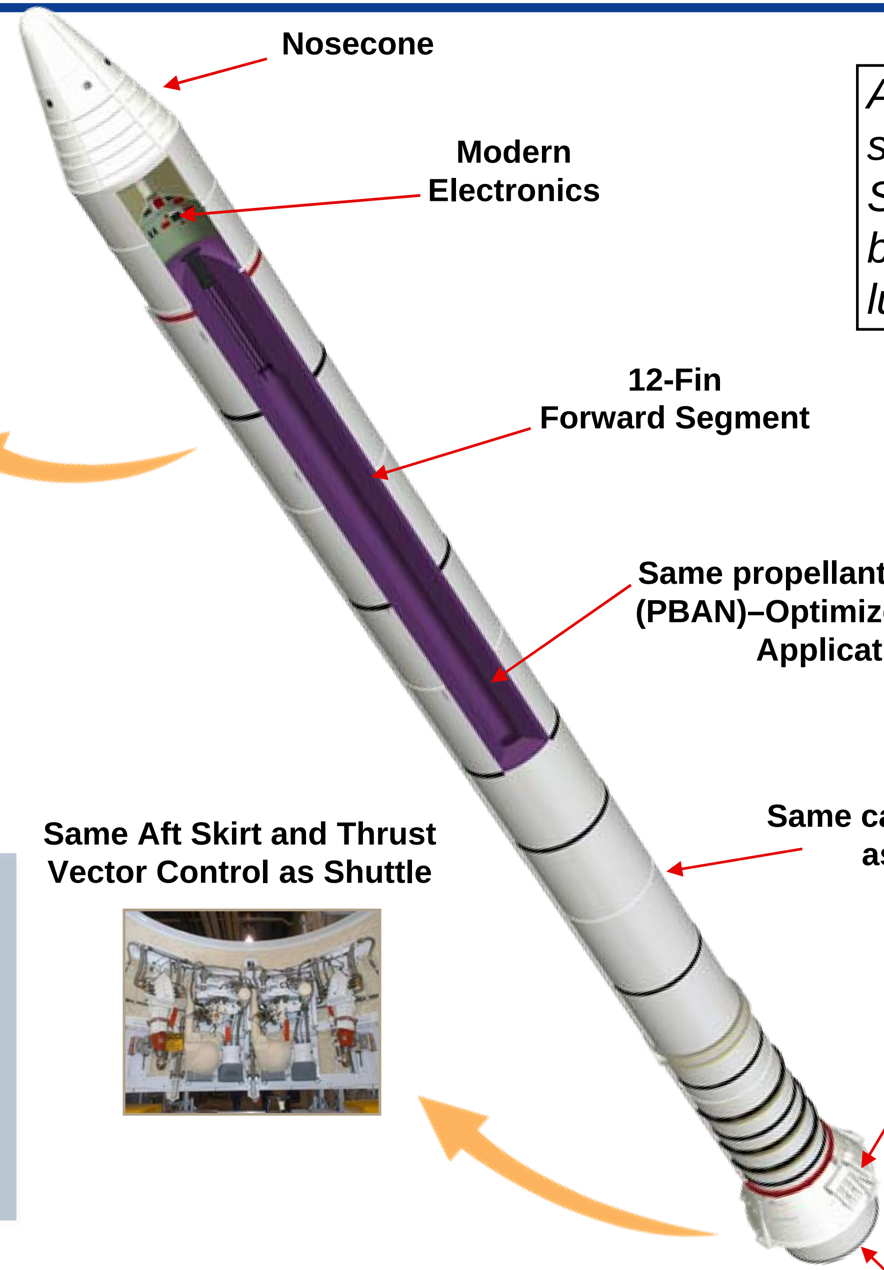
Nozzle Extension

Mass: 2.5 t (5,450 lbm)
Thrust: 1,300 kN (294k lbf) @ vac (100%)
Isp: 448 sec @ vac (100%)
Height: 4.7 m (185 in)
Diameter: 3.0 m (120 in)

Essentially identical to Ares I
- **Earth orbit loiter**
- **On-orbit restart**

Ares V Solid Rocket Booster (SRB)

Ares V SRB is similar to Space Shuttle and Ares I but optimized for lunar missions



Same Aft Skirt and Thrust Vector Control as Shuttle

Each Booster:

Mass: 791.5 t (1,744.9K lbm)

Thrust: 16.86 MN (3.79M lbf)

Burn Duration: 126 sec

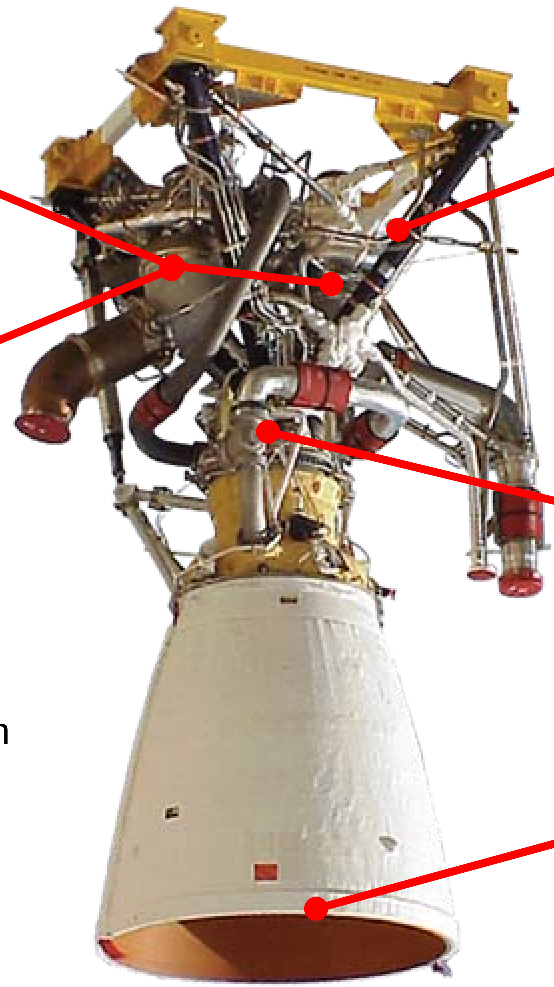
Height: 59 m (193 ft)

Diameter: 3.7 m (12 ft)

Core Stage Upgraded USAF RS-68B Engine

* Redesigned turbine nozzles to increase maximum power level by ≈ 2%

Helium spin-start duct redesign, along with start sequence modifications, to help minimize pre-ignition free hydrogen



Redesigned turbine seals to significantly reduce helium usage for pre-launch

* Higher element density main injector improving specific impulse

Other RS-68A upgrades or changes that may be included:

- Bearing material change
- New Gas Generator igniter design
- Improved Oxidizer Turbo Pump temp sensor
- Improved hot gas sensor
- 2nd stage Fuel Turbo Pump blisk crack mitigation
- Cavitation suppression
- ECU parts upgrade

Increased duration capability ablative nozzle

* **RS-68A Upgrades**