

# **Ares V and RS-68B**

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**JANNAF LPS Technical Steering Group**  
**RS-68/-68A/-68B Specialist Session**

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# ARES V and RS-68B

## Abstract

Ares V is the heavy lift vehicle NASA is designing for lunar and other space missions. It has significantly more lift capability than the Saturn V vehicle used for the Apollo missions to the moon. Ares V is powered by two recoverable 5.5 segment solid rocket boosters and six RS-68B engines on the core stage. The upper stage, designated as the Earth Departure Stage, is powered by a single J-2X engine. This paper provides an overview of the Ares V vehicle and the RS-68B engine, an upgrade to the Pratt & Whitney Rocketdyne RS-68 engine developed for the Delta IV vehicle.

## Constellation Program

The Constellation Program includes the Ares I & V launch vehicles, the Orion crew exploration vehicle, the Altair lunar lander and their associated missions. Ares I launches the Orion and its crew, and Ares V launches the earth departure stage (EDS) and Altair with the crew's supplies. The Ares V earth departure stage and the Orion vehicle rendezvous and mate in earth orbit, and the EDS propels the vehicles to the moon or other destination. The Constellation Program vehicles are depicted in Figure 1.



Figure 1. Constellation Program Vehicles

Ares I and Orion are currently in full scale development with first operational flight scheduled for spring of 2014. The Ares I project has completed preliminary design (PDR), while the Orion project will conduct PDR in mid 2009. Ares V is currently in systems architectural definition study phase, and full scale development is planned to start in October 2010 with test flights beginning in 2018. NASA's Exploration roadmap is shown in Figure 2.

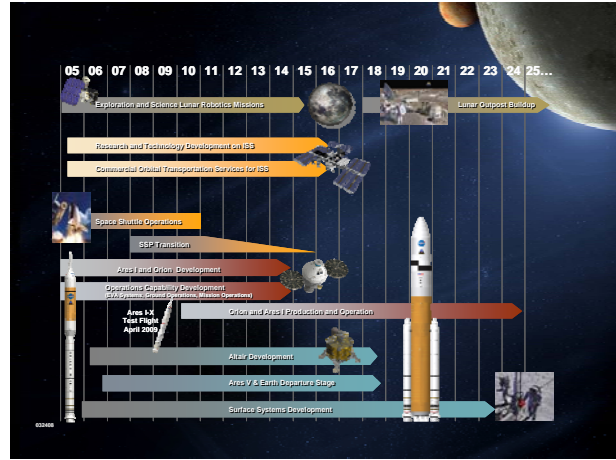


Figure 2. NASA's Exploration Roadmap

## Ares V

The Ares V is built upon a foundation of proven technologies from the Space Shuttle, Ares I and Saturn V vehicles as shown in Figure 3. The reusable solid rocket motors are derived from the Space Shuttle and Ares I boosters. The core stage tank includes technologies from the Space Shuttle program but will be built to the larger 33 foot diameter used on the Saturn V tanks. The J-2X engine, that powers the earth departure stage, has restart capability and will be a variant of the Ares I upper stage engine that was derived from the J-2 engine that powered the Saturn V S-II and S-IVB stages.

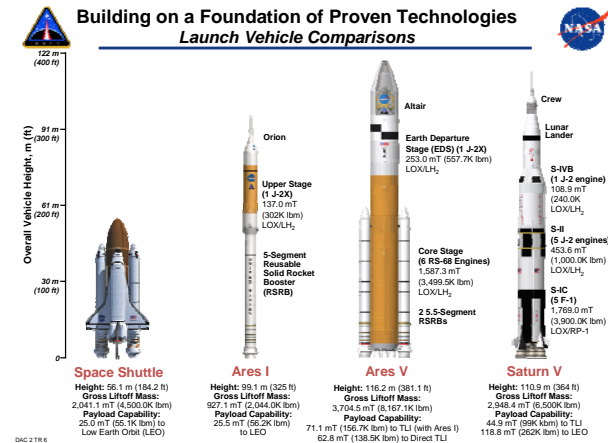


Figure 3. Ares V Technical Foundation

The versatile, heavy-lift Ares V is a two-stage, vertically stacked launch vehicle that is capable of delivering 414,000 pounds (188 metric tons) to low-Earth orbit. Working together with the Ares I crew launch vehicle, the Ares V can send nearly 157,000 pounds (71 metric tons) to the moon. The Ares V payload capability is

approximately 50 percent greater than the Saturn V. Payload capabilities to various orbits along with the payload envelop information are shown in Figure 4.

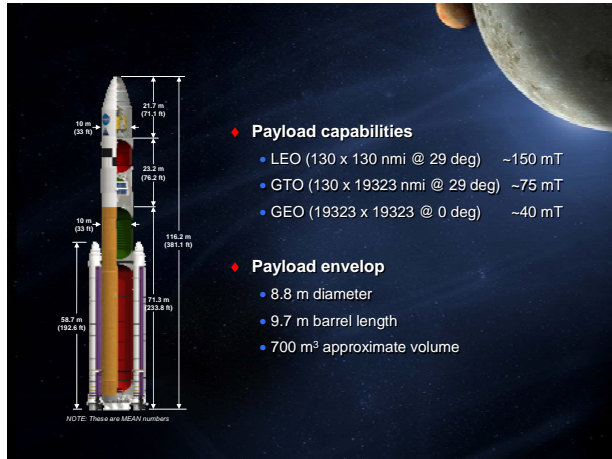


Figure 4. Ares V Capabilities for Other Missions

Ares V is composed of several elements as shown in Figure 5. The first stage includes the two recoverable 5.5-segment PBAN-fueled boosters that are derived from the 4 –segment Shuttle SRB and 5-segment Ares I first stage boosters designed and manufactured by ATK. The core stage includes six RS-68B engines derived from the Pratt & Whitney Rocketdyne RS-68 engine used on the United Launch Alliance Delta IV vehicle. The 71.3 meter long core stage has composite structures and includes aluminum-lithium tanks that are 10 meters in diameter. The earth departure stage includes an interstage, loiter skirt, aluminum-lithium tanks, composite structure, instrument unit with the primary Ares V avionics system. Other elements of the Ares V include the payload shroud and Altair lunar lander.



Figure 5. Ares V Elements (Vehicle 51.00.48)

As the Constellation Program has matured, the Ares V requirements and capabilities have evolved. Trade studies have evaluated payload capability as a function

of tank size, as well as solid booster and RS-68 engine design and performance options. Figure 6 shows some of the preliminary study results and opportunities for payload margin. The vehicle design has several specific practical limits and constraints. For example, the height of the door in the Vertical Assembly Building (VAB) at the Kennedy Space Center limits the height of the Ares V. Additionally, the diameter of 10 meters is considered a practical limit due to fabrication and shipping capabilities. Also, the standard RSRM segment length combined with a structural requirement for the attachment point of the RSRB to be between the core stage hydrogen and oxygen tanks, and, Michoud Assembly Facility building limitations constrain the length of the core stage.

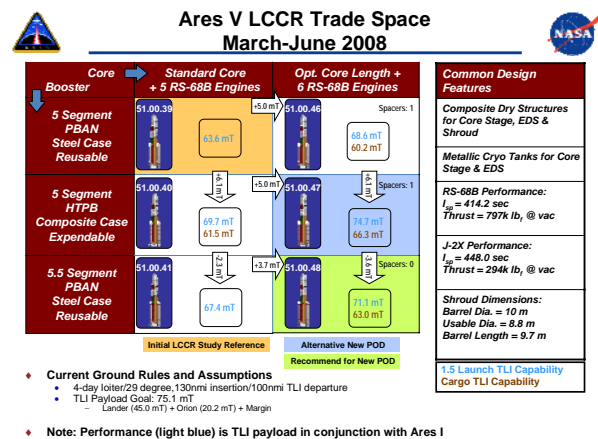


Figure 6. Ares V Trade Study

One of the early vehicle studies planned for the new 6-engine baseline is analysis of the base heating. The two RSRB and six RS-68B engines with their turbine exhaust ducted above the nozzle exit plane create a significant thermal environment. Various engine layout schemes are being studied as shown in Figures 7 and 8. An example of a key integration trade is the engine layout for efficient accommodation of thrust loads while optimizing the vehicle performance and outer mold line. Factors include favorably handled thrust loads with engines on the outer stage circumference (like Saturn V) and the impact of a protective skirt that adds weight and creates aerodynamic drag. These studies and others will be conducted in the architectural concept definition phase over the next two years prior to the official start of Design Analysis Cycle 1 beginning in October 2010 as shown Figure 9. With a 2011 government fiscal year start for full scale development, the Ares V will have its first flight in 2018. Main propulsion test article (MPTA) testing of the core stage will prove out the integration of the RS-68B engines with the cores stage.

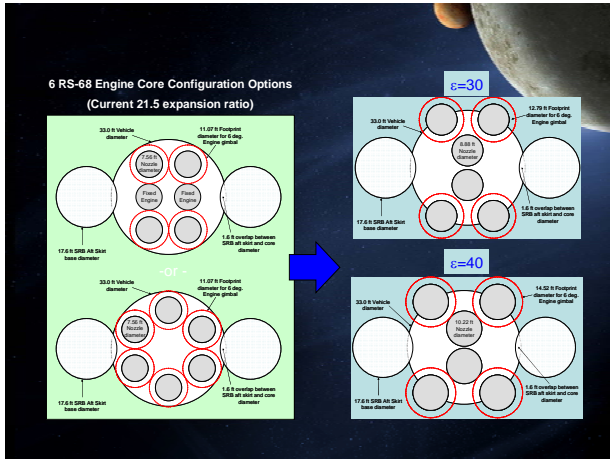


Figure 7. Ares V Engine Layout Study

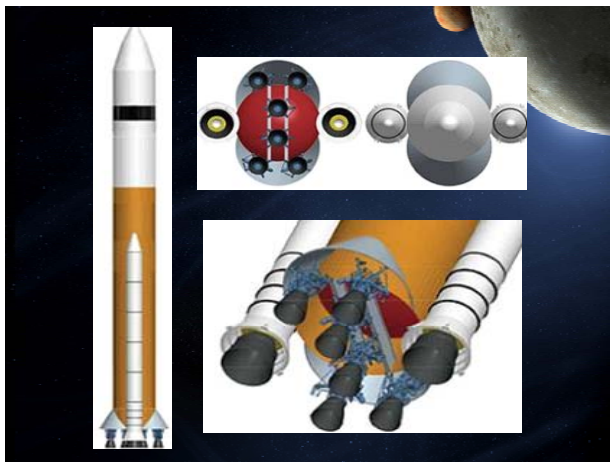


Figure 8. View of Ares V with Engine Skirt

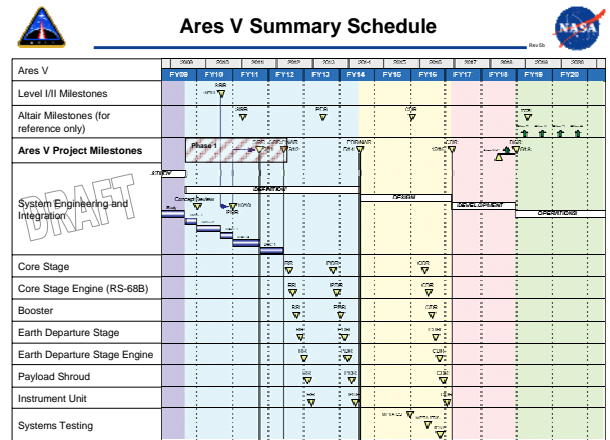


Figure 9. Ares V Schedule

### RS-68B Engine

The RS-68B engine is derived from the Pratt & Whitney Rocketdyne engine that is flying on the Delta IV vehicle. The RS-68B has additional modifications and benefits from the RS-68A development program as shown in Figure 10. Ares V requires the thrust and specific impulse performance of the RS-68A engine including the reliability improvements developed under the Assured Access To Space (AATS) program.

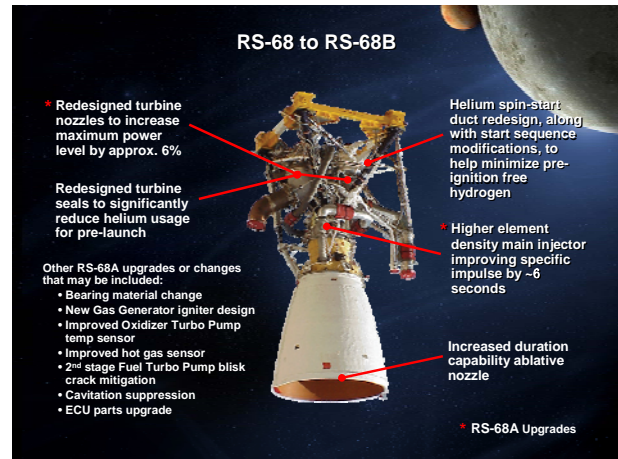


Figure 10. RS-68A and RS-68B Upgrades

The RS-68A program consists of two major design changes. Engine thrust is increased 39,000 pounds force by modifying the turbine nozzles from axis-symmetric to 3 dimensional to reduce turbine blade loading and to expand the operational range of both the fuel and oxidizer turbopumps. Specific impulse is improved by increasing the number of the main injector combustion elements which improves mixing and combustion efficiency. Other AATS funded improvements to the RS-68A engine include a new bearing material that is more resistant to stress corrosion cracking, improved processing of the 2<sup>nd</sup> stage fuel turbopump blisk to reduce cracking potential, improved oxidizer turbopump chill sensor and an improved hot gas temperature sensor. An improved gas generator igniter that has less foreign object debris potential is also under development and expected to be included in the RS-68A certification program.

NASA has requested three changes for the RS-68B for Ares V. First is to reduce the amount of free hydrogen at engine start to mitigate the potential for fire around the vehicle and need for added thermal protection. The second is to reduce the amount of helium purge gas used by the engine which currently taxes the Cape Canaveral Air Force Station (CCAFS) helium infrastructure from both a flow rate and total usage standpoint for the 3-engine Delta IV Heavy vehicle. The third change is to modify the ablative nozzle to accommodate the duration

requirements of the Ares V mission. Figure 11 shows how the RS-68 engine is modified for both the RS-68A and RS-68B configurations. The proposed RS-68B design changes were studied from early 2006 to May 2007, and the results are summarized below.

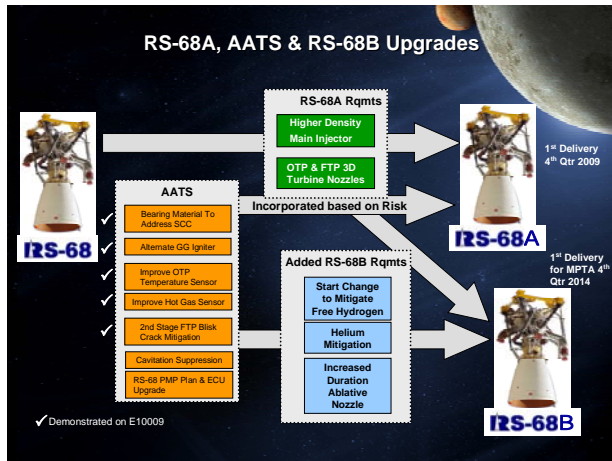


Figure 11. RS-68A and RS-68B Upgrades

The free hydrogen reduction is being accomplished by changing the start sequence and helium spin start hardware. A software change for valve sequencing to reduce the hydrogen lead time by 1 second will result in approximately a 15 percent reduction in free hydrogen. The helium spin start inlet port is being changed to provide more helium flow to the oxidizer turbopump to speed up its start contributing to a total reduction in free hydrogen of approximately 50 percent. With these improvements, the amount of free hydrogen on the launch pad will be about equivalent to what is released by three Space Shuttle Main Engines (SSME). Figure 12 shows engineering model of test rig and test hardware that will be used to validate the helium spin start analysis and design change.



Figure 12. Helium Spin Start Test Rig and Test Hardware

The effect of free hydrogen on the launch pad is also a function of the pad design and environment (weather / wind) the day of launch. The Delta IV pad has an enclosed or cover flame trench, while the Space Shuttle launch pad is open. Computational fluid dynamics (CFD) analyses of an Ares V with the previous 5-engine configuration were performed for the current start configuration, one with software start sequence change only, and one with both the software and helium spin start design change. Results are shown in Figure 13. The plumes are 1000F isotherms at when the engine exhaust would start to aspirate the plume out the flame trench. As noted by the figure, hydrogen plume size and height is significantly reduced with the new start design.

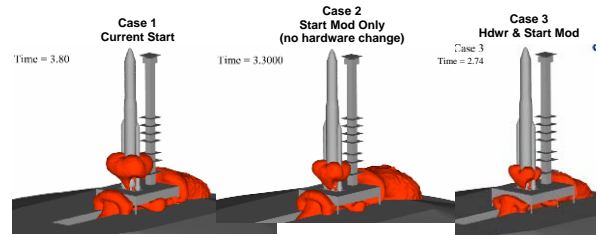


Figure 13. CFD Analysis Comparison of Current Start, Sequence Change Only, and Sequence Change with Helium Spin Start Modification.

The reduction in helium consumption by the engine will be accomplished redesigning the oxidizer turbopump interpropellant seal. The current labyrinth seal will be replaced with a segmented carbon contact seal similar to what is used on the J-2X engine. This seal is expected to reduce both the maximum flow rate and total helium consumption to the level of three SSME's. Figure 14 shows comparison of maximum flow rate of current engine design versus floating carbon seal and segmented carbon contact seal.

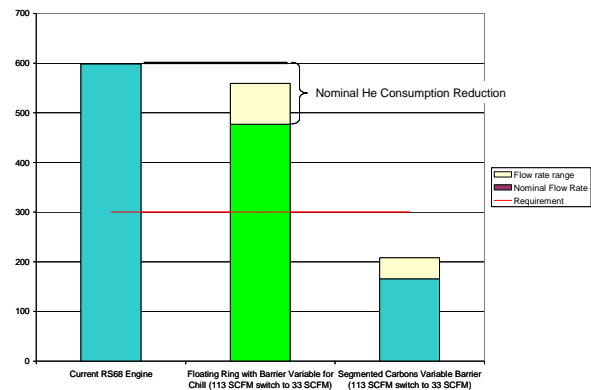


Figure 14. RS-68 Oxidizer Turbopump Interpropellant Seal Design Comparison

The change to the ablative nozzle to permit it to run at the enhanced thrust level for full duration of approximately 330 seconds was expected to result in a weight increase of less than 150 pounds. However, since the 2006 study a material obsolescence issue with the ablative material has been encountered and a new material is being implemented on the RS-68A program. The impact to the RS-68B nozzle is not expected to be significant nor require early risk reduction effort.

Another part of the early RS-68B study was to assess the gaps between the RS-68 design certification and the NASA Constellation Program requirements. Seventeen major Constellation specifications containing 1770 requirements were evaluated. Of these, 76 percent were considered applicable to the engine, and of these only 55 percent were compliant. The majority of requirements not met deal with NASA specific review boards and other oversight provisions. A thorough review and waiver process will need to be conducted to resolve these differences and to maintain a common configuration for the components and engine for the Ares V and Delta IV applications.

Although the Ares V and RS-68B full scale development will not begin in earnest until October 2010, there is benefit in conducting risk reduction tasks to preserve the RS-68B 2014 delivery schedule for the Main Propulsion Test Article. See Figure 15 for the preliminary RS-68B development schedule. These include preliminary effort on the hydrogen and helium mitigation requirements as well as engine-vehicle interface and integration studies as listed below.

- Engine-vehicle interface and integration studies
- RS-68B performance trades
- Engine layout trade studies
- Base heating mitigation and turbine exhaust ducting trades
- Helium Spin Start (HeSS) DDT&E
- OTP interpropellant seal design
- Requirements assessment

## Summary

The Ares V with its heavy lift capability will be a national asset not only for NASA's lunar and future Mars missions, but also for other government strategic and scientific missions. The RS-68B engine is a key element of the Ares V, and its success is dependent upon the success of the current RS-68A upgrade program as well as other AATS and NASA upgrades.

## Acknowledgments

The authors wish to thank the following for their efforts on the Ares V and RS-68 program and their contributions to this paper.

Phil Sumrall, NASA, MSFC  
 Martin Burkey, The Schafer Corporation  
 Steve Ebert, Pratt & Whitney Rocketdyne  
 Craig Stoker, Pratt & Whitney Rocketdyne

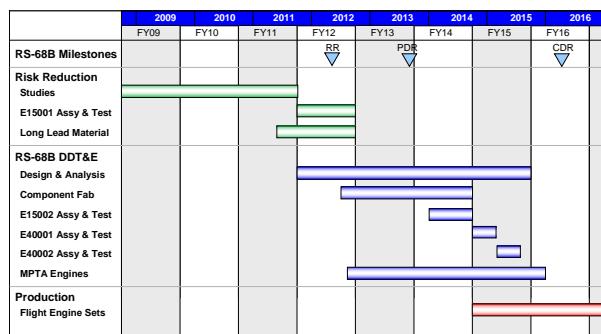


Figure 15. RS-68B Preliminary Development Schedule



National Aeronautics and Space Administration

## JANNAF - Liquid Propulsion Subcommittee

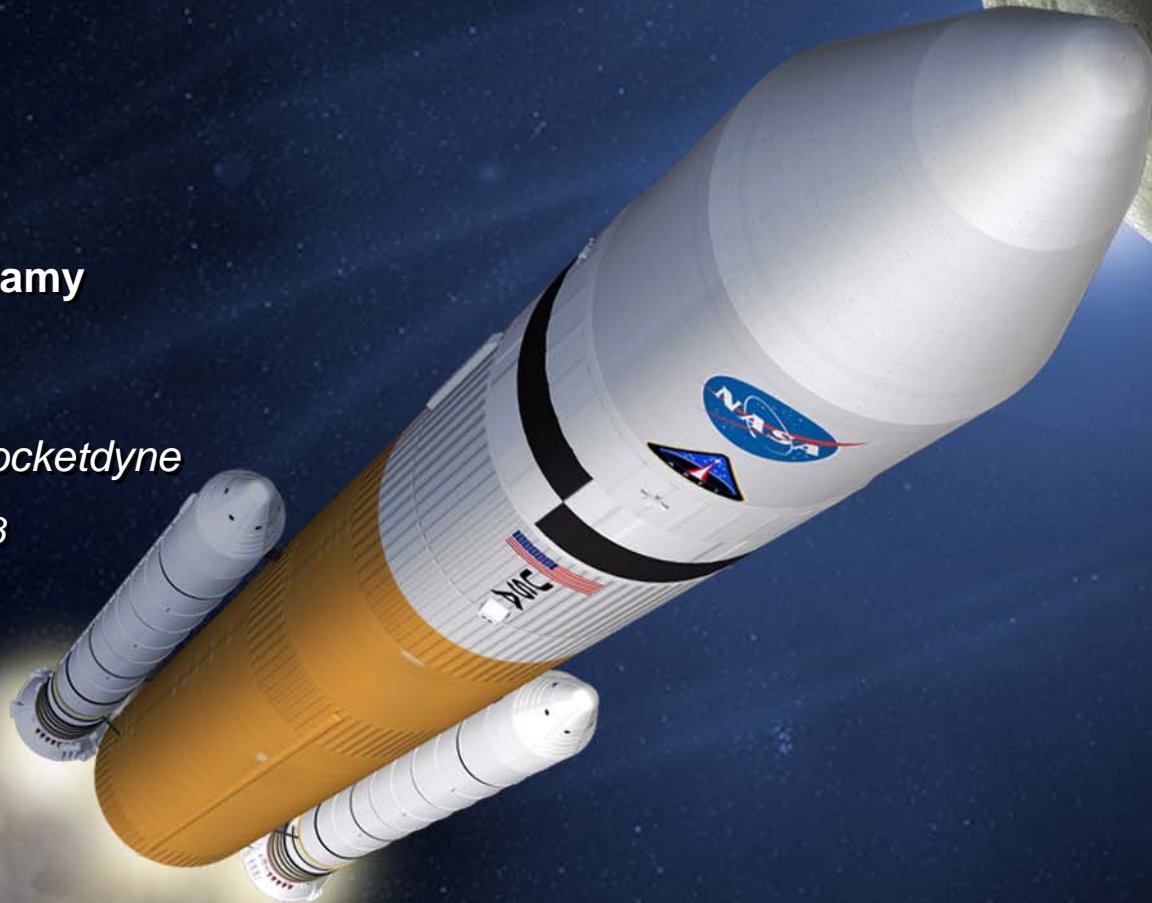
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**Jim Taylor**  
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*AFSPC*

**Fritz Kuck**  
*Pratt & Whitney Rocketdyne*

*December 8-12, 2008*

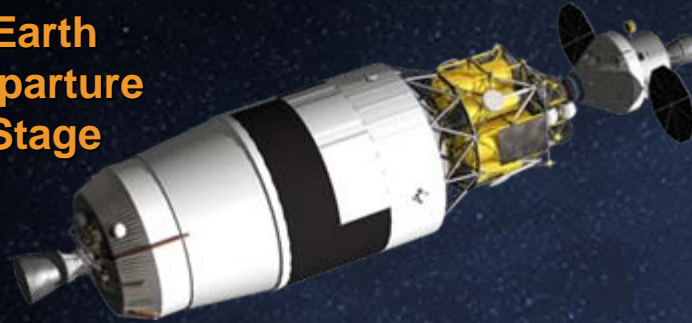


# Ares V and RS-68B



# Constellation Program Vehicles

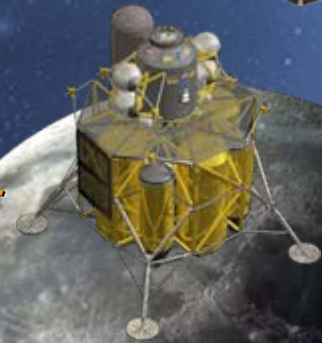
Earth  
Departure  
Stage



Orion  
Crew Exploration  
Vehicle



Altair  
Lunar  
Lander



Ares V  
Cargo Launch  
Vehicle



Ares I  
Crew Launch  
Vehicle





# NASA's Exploration Roadmap



05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25...

**Exploration and Science Lunar Robotics Missions** (05-17)

**Lunar Outpost Buildup** (18-25...)

**Research and Technology Development on ISS** (05-17)

**Commercial Orbital Transportation Services for ISS** (05-17)

**Space Shuttle Operations** (05-10)

**SSP Transition** (05-17)

**Ares I and Orion Development** (05-17)

**Operations Capability Development (EVA Systems, Ground Operations, Mission Operations)** (05-17)

**Orion and Ares I Production and Operation** (18-25...)

**Ares I-X Test Flight April 2009** (09)

**Altair Development** (10-17)

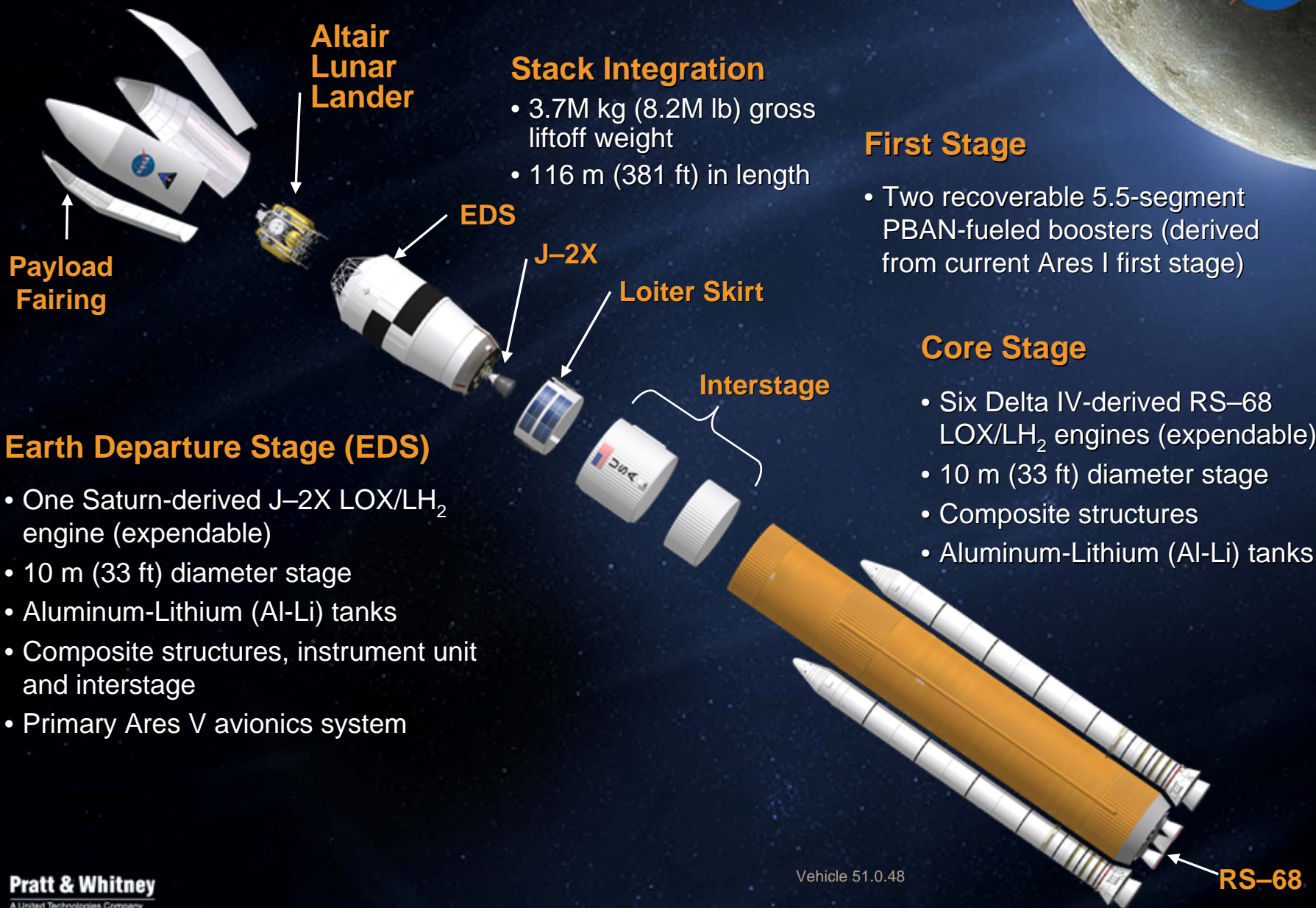
**Ares V & Earth Departure Stage** (10-17)

**Surface Systems Development** (10-25...)

032408



# Ares V Elements



## Stack Integration

- 3.7M kg (8.2M lb) gross liftoff weight
- 116 m (381 ft) in length

## First Stage

- Two recoverable 5.5-segment PBAN-fueled boosters (derived from current Ares I first stage)

## Core Stage

- Six Delta IV-derived RS-68 LOX/LH<sub>2</sub> engines (expendable)
- 10 m (33 ft) diameter stage
- Composite structures
- Aluminum-Lithium (Al-Li) tanks

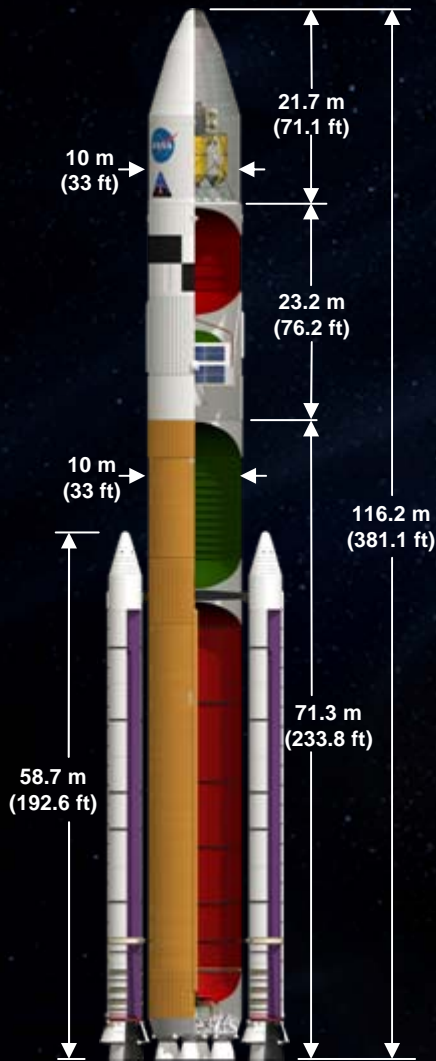
## Earth Departure Stage (EDS)

- One Saturn-derived J-2X LOX/LH<sub>2</sub> engine (expendable)
- 10 m (33 ft) diameter stage
- Aluminum-Lithium (Al-Li) tanks
- Composite structures, instrument unit and interstage
- Primary Ares V avionics system

Vehicle 51.0.48

RS-68

# Ares V Capabilities for Other Missions



NOTE: These are MEAN numbers

## ◆ Payload capabilities

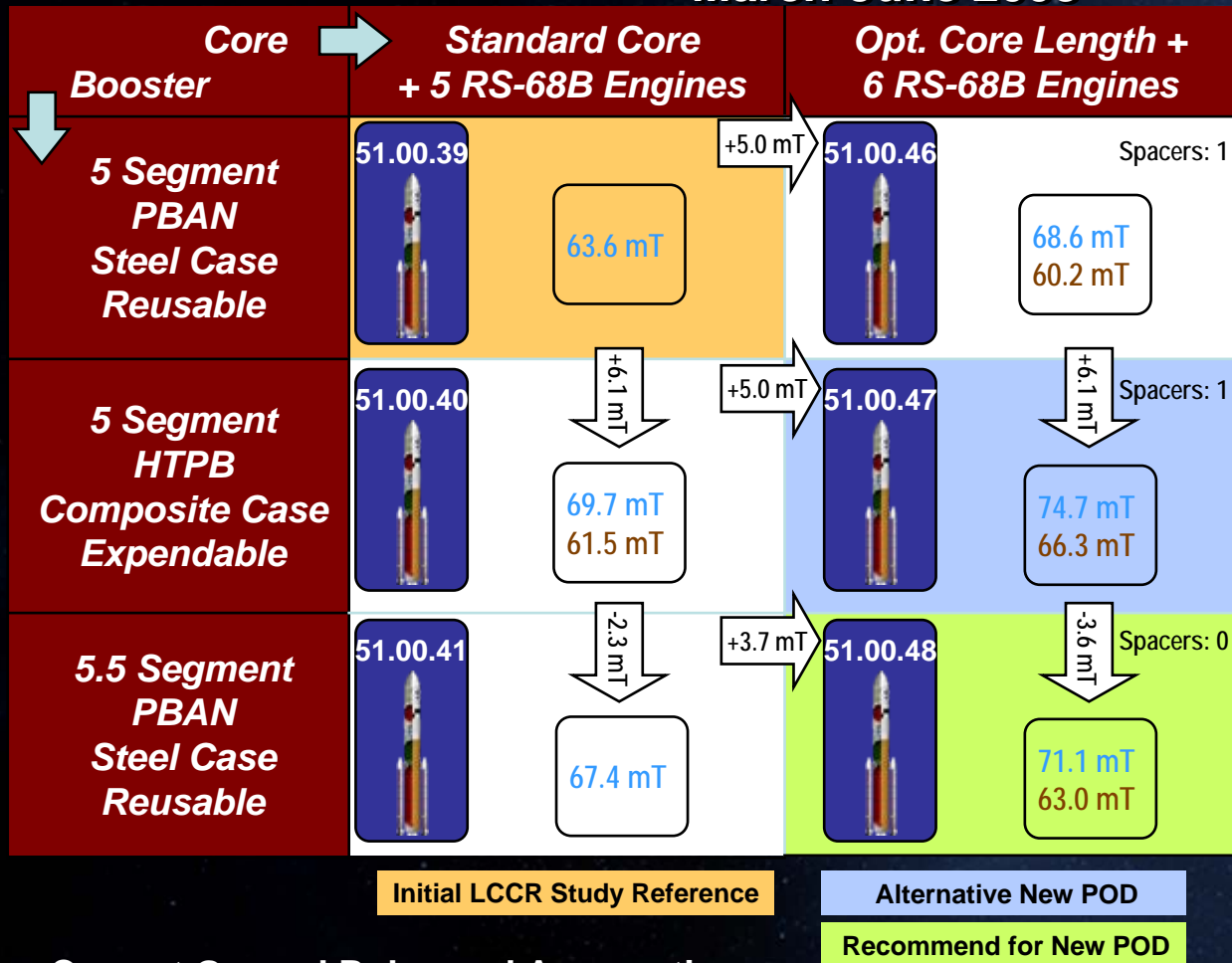
- LEO (130 x 130 nmi @ 29 deg) ~150 mT
- GTO (130 x 19323 nmi @ 29 deg) ~75 mT
- GEO (19323 x 19323 @ 0 deg) ~40 mT

## ◆ Payload envelop

- 8.8 m diameter
- 9.7 m barrel length
- 700 m<sup>3</sup> approximate volume

# Ares V LCCR Trade Space

## March-June 2008



### Common Design Features

Composite Dry Structures for Core Stage, EDS & Shroud

Metallic Cryo Tanks for Core Stage & EDS

#### RS-68B Performance:

$I_{sp} = 414.2 \text{ sec}$

Thrust = 797k  $lb_f$  @ vac

#### J-2X Performance:

$I_{sp} = 448.0 \text{ sec}$

Thrust = 294k  $lb_f$  @ vac

#### Shroud Dimensions:

Barrel Dia. = 10 m

Usable Dia. = 8.8 m

Barrel Length = 9.7 m

1.5 Launch TLI Capability  
Cargo TLI Capability

### Current Ground Rules and Assumptions

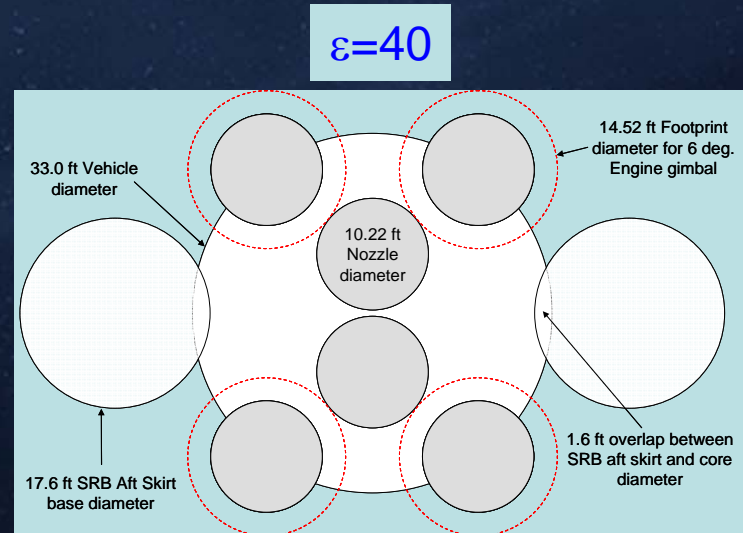
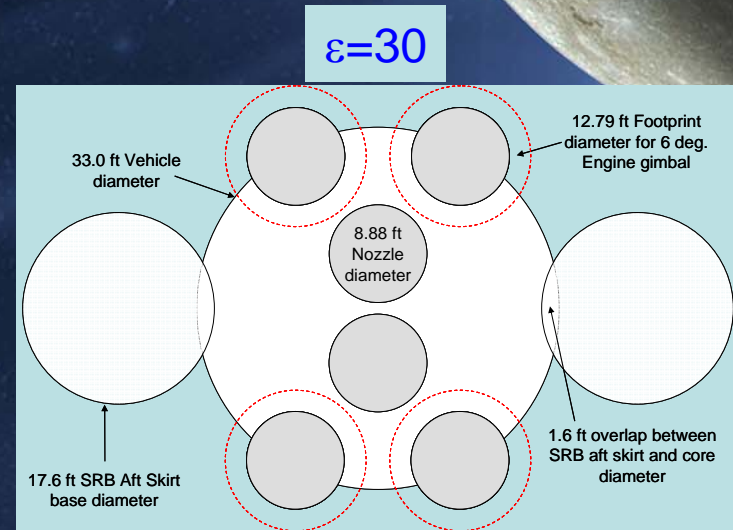
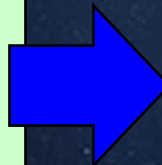
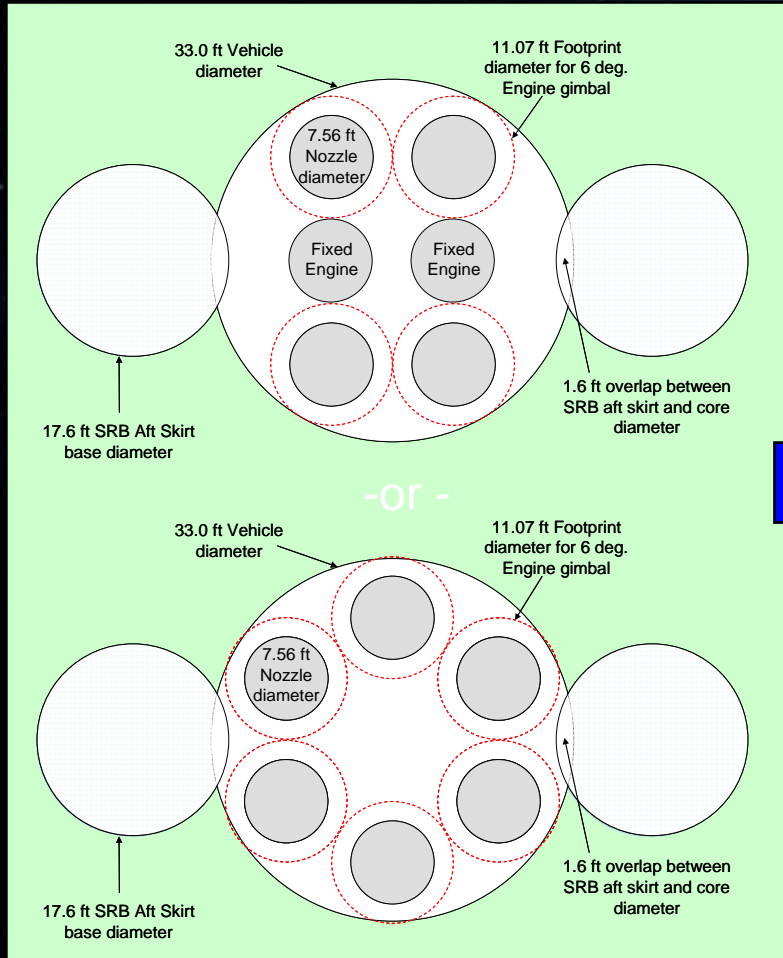
- 4-day loiter/29 degree, 130nmi insertion/100nmi TLI departure
- TLI Payload Goal: 75.1 mT
  - Lander (45.0 mT) + Orion (20.2 mT) + Margin

Note: Performance (light blue) is TLI payload in conjunction with Ares I

# Ares V Engine Layout Study



## 6 RS-68 Engine Core Configuration Options (Current 21.5 expansion ratio)



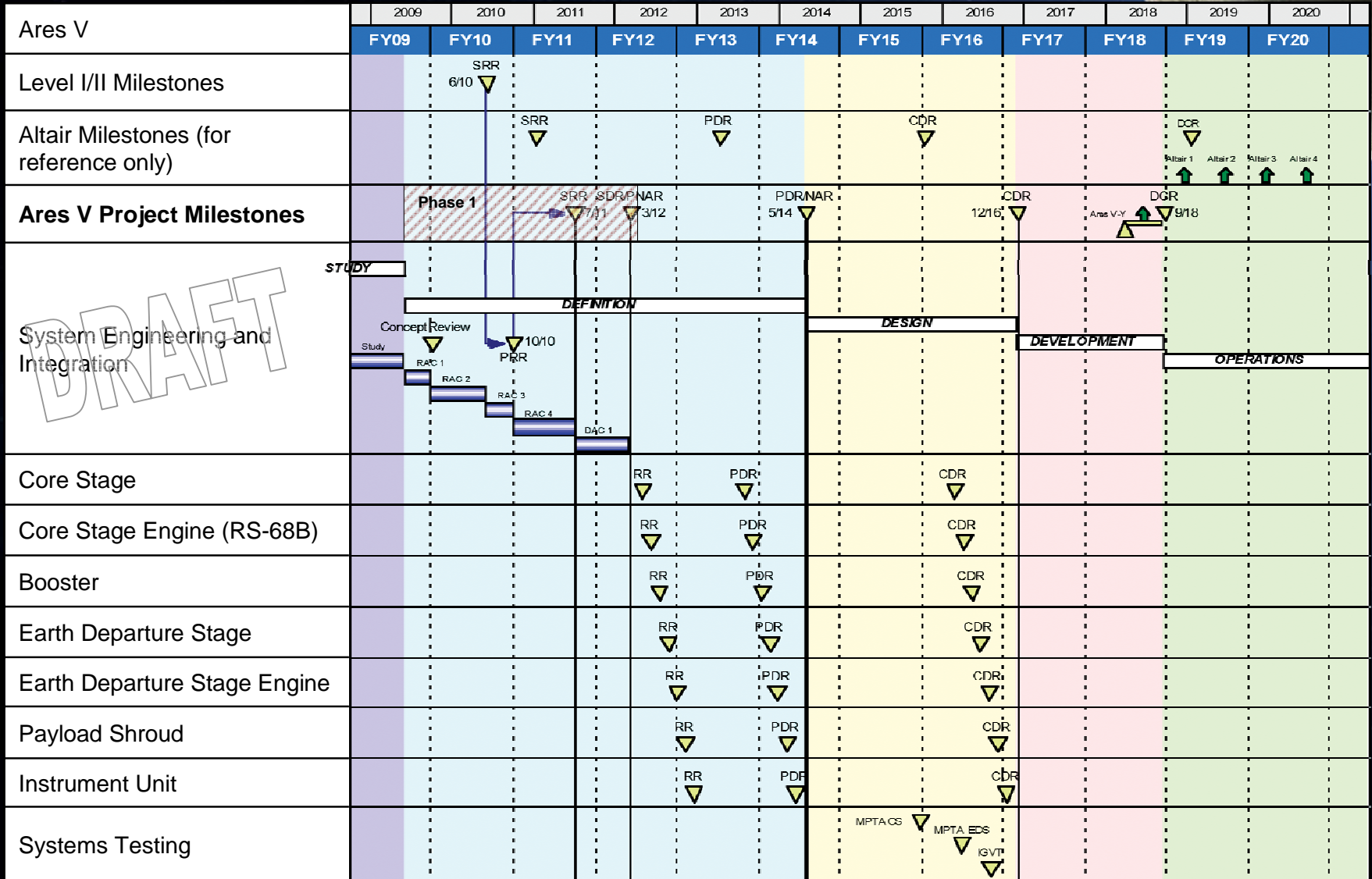


# Ares V Engine Layout Trade Example



- ◆ Vehicle thrust loads favorably handled with engines on outer stage circumference
- ◆ Engines positioned on stage circumference require protective skirt – adds weight
- ◆ Skirt creates drag and impacts vehicle performance

# Ares V Schedule



DRAFT



# RS-68 to RS-68B

\* Redesigned turbine nozzles to increase maximum power level by approx. 6%

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

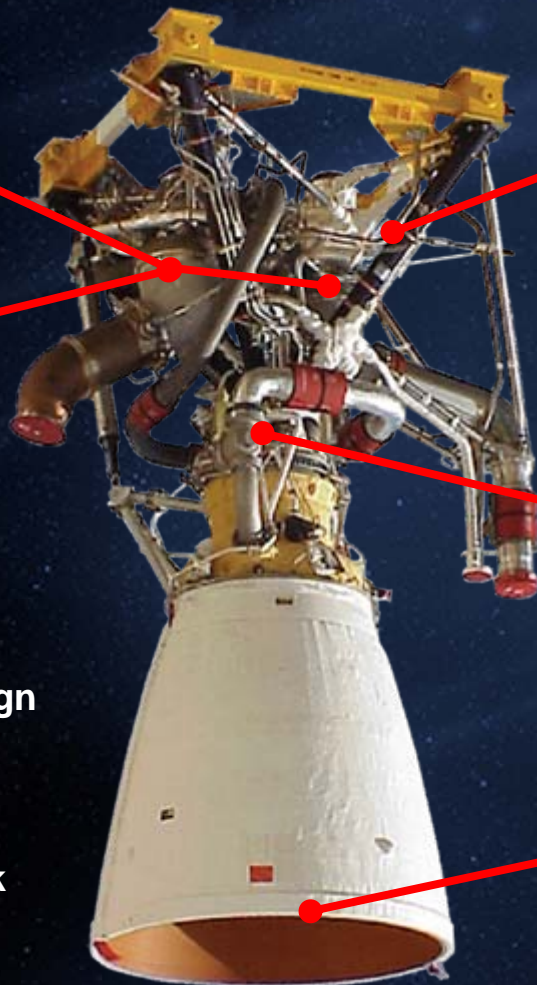
Other RS-68A upgrades or changes that may be included:

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

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

\* Higher element density main injector improving specific impulse by ~6 seconds

Increased duration capability ablative nozzle



\* RS-68A Upgrades



# RS-68A, AATS & RS-68B Upgrades



**RS-68**

- ✓
- ✓
- ✓
- ✓
- ✓

**AATS**

- Bearing Material To Address SCC
- Alternate GG Igniter
- Improve OTP Temperature Sensor
- Improve Hot Gas Sensor
- 2nd Stage FTP Blisk Crack Mitigation
- Cavitation Suppression
- RS-68 PMP Plan & ECU Upgrade

**RS-68A Rqmts**

- Higher Density Main Injector
- OTP & FTP 3D Turbine Nozzles

Incorporated based on Risk

**Added RS-68B Rqmts**

- Start Change to Mitigate Free Hydrogen
- Helium Mitigation
- Increased Duration Ablative Nozzle



**RS-68A**

1<sup>st</sup> Delivery  
4<sup>th</sup> Qtr 2009



**RS-68B**

1<sup>st</sup> Delivery  
for MPTA 4<sup>th</sup>  
Qtr 2014

✓ Demonstrated on E10009

# RS-68B Project Status



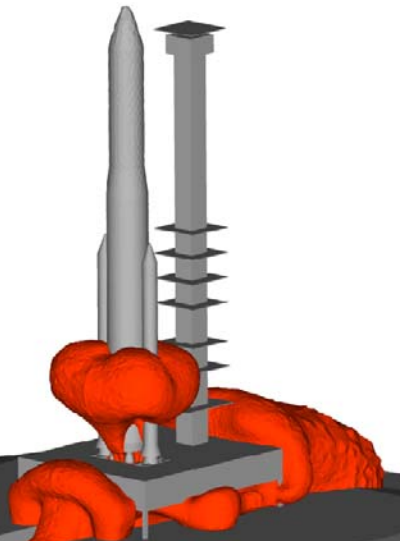
- ◆ **RS-68B study performed from early 2006 to May 2007**
- ◆ **Completed upgrades System Requirements Review**
  - Preliminary requirements for early Ares V configured vehicle
  - Identified gaps between Delta IV levied requirements and NASA Constellation Program requirements
  - Drafted Prime Item Development Specification for engine
- ◆ **Completed preliminary design reviews on upgraded components**
  - Oxidizer Turbopump (OTP) interpropellant seal for helium mitigation
  - Helium spin start system for hydrogen mitigation
  - Ablative nozzle redesign for 330 seconds duration at 108% power level

# Hydrogen Mitigation Launch Pad Analysis



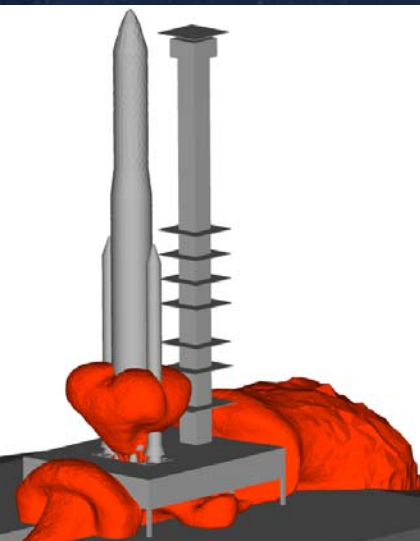
**Case 1**  
**Current Start**

Time = 3.80



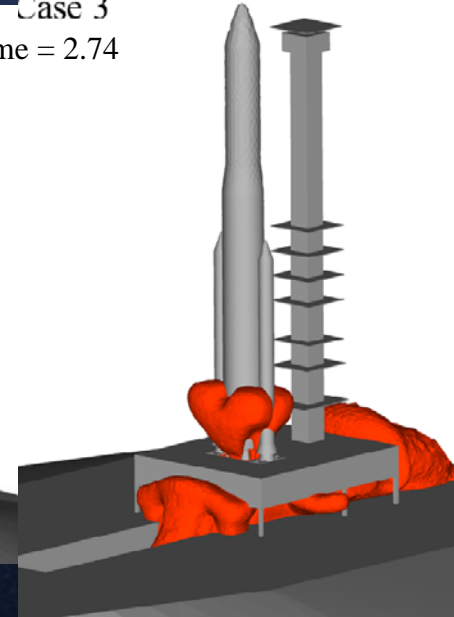
**Case 2**  
**Start Mod Only**  
**(no hardware change)**

Time = 3.3000



**Case 3**  
**Hdwr & Start Mod**

**Case 3**  
Time = 2.74



[Click Here for  
Animated Comparison](#)

# Ares V and RS-68B Integration and Risk Reduction Tasks for 2008-2010



- ◆ Engine-vehicle interface and integration studies
- ◆ RS-68B performance trades
- ◆ Engine layout trade studies
- ◆ Base heating mitigation and turbine exhaust ducting trades
- ◆ Helium Spin Start (HeSS) DT&E
- ◆ OTP interpropellant seal design
- ◆ Engine handling methods
- ◆ Requirements assessment

# RS-68B Preliminary Schedule

