Exploration Launch Projects RS-68B Engine Requirements for NASA's Heavy Lift Ares V

John P. Sumrall, J. Craig McArthur, and Matt Lacey
NASA Marshall Space Flight Center, Huntsville, AL 35812

Abstract

NASA’s Vision for Exploration requires a safe, efficient, reliable, and versatile launch vehicle capable of placing large payloads into Earth orbit for transfer to the Moon and destinations beyond. The Ares V Cargo Launch Vehicle (CaLV) will provide this heavy lift capability. The Ares V launch concept is shown in Fig. 1. When it stands on the launch pad at Kennedy Space Center late in the next decade, the Ares V stack will be almost 360 feet tall. As currently envisioned, it will lift 133,000 to 144,000 pounds to trans-lunar injection, depending on the length of loiter time on Earth orbit. This presentation will provide an overview of the Constellation architecture, the Ares launch vehicles, and, specifically, the latest developments in the RS-68B engine for the Ares V.

Fig. 1. Ares V launch concept.

1 Manager, Advanced Planning, Exploration Launch Projects Office.
2 Manager, Ares V Core Stage Element, Exploration Launch Projects Office.
3 Aerospace Engineer.
WSFL - 401 Presentation

Exploration Launch Projects

RS-68B – Engine Requirements for NASA’s Heavy Lift Ares V

John P. Sumrall
Manager, Advanced Planning
Marshall Space Flight Center

J. Craig McArthur
Acting Manager, Ares V Core Stage Element Office
Marshall Space Flight Center

Matt Lacey
Acting Engine Systems Lead
Marshall Space Flight Center

NRO/AIAA Space Launch Integration Forum
July 2007
Agenda

♦ Overview of the Ares Launch Vehicles
♦ Vehicle comparison
♦ Engine choice refinement
♦ RS-68B results so far
♦ Forward work and conclusions
Overview of the Exploration Launch Projects Architecture

- Safe, reliable, affordable space transportation
- Based on heritage hardware and legacy knowledge
- Separates cargo from crew
- Ares V (left) delivers heavy exploration cargo to Low Earth Orbit (LEO)
- Ares I (right) delivers crew and cargo to LEO for International Space Station and lunar missions

National Aeronautics and Space Administration
Shared heritage, shared hardware

Ares I

- 1 Shuttle-derived Reusable Solid Rocket Booster (RSRB) First Stage
- 1 J-2X LOx/LH₂ Upper Stage Engine

Ares V

- Core Stage
  - 5 RS-68 LOx/LH₂ Core Stage engines
  - 2 Ares I-derived RSRBs
- Earth Departure Stage (EDS)
  - 1 J-2X LOx/LH₂ Upper Stage Engine

Common hardware and procedures with Ares I to reduce development and operations costs

* Depending on length of in-orbit LEO lifetime

National Aeronautics and Space Administration
Ares V mission profile

- **Launch**
  - Time: 1 sec
  - Thrust-to-Weight: 1.38
  - GPM: 1.125 (2,000 lbm)

- **SRB Separation**
  - Time: 120.9 sec
  - Altitude: 109.7 km
  - Mach: 6.77
  - Dynamic Pressure: 99 psi

- **Main Engine Cutoff**
  - Time: 205.3 sec
  - Altitude: 432.9 km

- **EDS Engine Cutoff**
  - Time: 797.2 sec
  - Sub-Orbital Run Duration: 441.9 sec
  - Impactor Weight: 6,089.5 lbm
  - Orbital Altitude: 235 km on @ 29.5°

- **EDS TU Run**
  - Orbital Altitude: 100 mm sec @ 29.5°
  - Burn Duration: 3600.0 sec

- **CEV Release & Dock on ISS**
  - Time: Assumed Up to 14 Days
  - Orbital Altitude Assumed to Disperse to 100 mm

- **Lunar Lander/CEV Separation**

- **EDS Disposal**

National Aeronautics and Space Administration

5
The Lunar Mission Scenario

MOON

J

Ascent
Stage
Expended

Lunar Lander
Performs LOI

100 km
Low Lunar Orbit

Earth Departure
Stage Expended

Service
Module
Expended

Direct Entry
Land Landing

Vehicles Not
to Scale

Low
Earth
Orbit

EARTH

National Aeronautics and Space Administration
Building on a Foundation of Proven Technologies
- Launch Vehicle Comparisons -

Space Shuttle
- Height: 184.2 ft
- Gross Liftoff Mass: 4.5M lb
- 55k lbm to LEO

Ares I
- Height: 328 ft
- Gross Liftoff Mass: 2.0M lb
- 52k lbm to LEO (effective)

Ares V
- Height: 362 ft
- Gross Liftoff Mass: 7.3M lb
- 133-144k lbm to TLI in Dual-Launch Mode with Ares I

Delta IV-H
- Height: 362 ft
- Gross Liftoff Mass: 1.9M lb
- 48k lbm to LEO

Saturn V
- Height: 364 ft
- Gross Liftoff Mass: 6.5M lb
- 55k lbm to TLI

* Depending on length of on-orbit LEO booster time

National Aeronautics and Space Administration
Refining the Concept

 Exploration System Architecture Study
  • Ares V baseline:
    2 RSRBs,
    5 Space Shuttle Main Engines (SSMEs),
    27.5 foot diameter Shuttle-derived Core Stage

 Bottom-Up Review
  • RS-68 replaces SSME
    - Fewer parts
    - Less labor
    - Simpler to modify
    - Synergy with USAF engine upgrades
    - Delta IV flight experience reduces technical risk
  • 33 foot diameter Saturn V-class Core Stage
The Department of Defense is already pursuing changes to improve power level (turbine inlet nozzles) and performance (ISP – higher injector element density). The Air Force, through its Assured Access to Space program, is seeking changes to improve the engine's robustness (eliminate cracking of second stage blisk). NASA's desired upgrades would improve engine operations and safety (free hydrogen reduction). The proposed common engine, designated RS-68B, would build on the RS-68A upgrades on a non-interference basis.
Early Testing

- RS-68 (left) and J-2X (right) subscale injector testing at MSFC, 2006-2007
- 29 RS-68-focused, 32 J-2X-focused
- 28-, 40-, & 58-element injector inserts
- Thrust levels: less than 20,000 lbf
- Chamber pressures: 850-1,500 psig
- Mixture Ratios: 4.8-6.9
- Fuel manifold temperatures: 100-300°. Rankin
- Commonality

Bench and subscale testing was used to further drive risk out of the project early. Subscale testing was very cost effective. Data obtained could be leveraged by several projects at a cost of roughly $250,000.

Bench and subscale testing was used to further drive risk out of the project early. Subscale testing was very cost effective. Data obtained could be leveraged by several projects at a cost of roughly $250,000.
The Department of Defense is already pursuing changes to improve power level (turbine inlet nozzles) and performance (ISP – higher injector element density). The Air Force, through its Assured Access to Space program, is seeking changes to improve the engine's robustness (eliminate cracking of second stage blisk). NASA's desired upgrades would improve engine operations and safety (free hydrogen reduction). The proposed common engine, designated RS-68B, would build on the RS-68A upgrades on a non-interference basis.
A key part of the Ares V effort is driving risk and cost out of the system early on by evaluating the impact of design on operational and recurring costs. Some examples are shown here. Facility trade studies sought to ensure the lowest fixed cost. Analyses are used to help refine requirements. For instance, analyses showed that hardware mods, as well as software mods, would be required to significantly reduce free hydrogen on the launch pad, a risk to the safety of the vehicle.
A key part of the Ares V effort is driving risk and cost out of the system early on by evaluating the impact of design on operational and recurring costs. Some examples are shown here. Facility trade studies sought to ensure the lowest fixed cost. Analyses are used to help refine requirements. For instance, analyses showed that hardware mods, as well as software mods, would be required to significantly reduce free hydrogen on the launch pad, a risk to the safety of the vehicle.
A key part of the Ares V effort is driving risk and cost out of the system early on by evaluating the impact of design on operational and recurring costs. Some examples are shown here. Facility trade studies sought to ensure the lowest fixed cost. Analyses are used to help refine requirements. For instance, analyses showed that hardware mods, as well as software mods, would be required to significantly reduce free hydrogen on the launch pad, a risk to the safety of the vehicle.
Free hydrogen study: Pad flow entrainment

- Other points of attack
The path ahead: High Value Targets

- Risk reduction efforts
- Continued cooperation and insight
- Adapt to future funding opportunities and challenges

### Ares V Consolidated Schedule

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ares V Major Milestones</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ares V Risk Reduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ares V Design Analysis Cycles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Stage Milestones</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Stage Engine (RS-888)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Stage Fabrication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Stage Engine Fabrication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Stage Engine Assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Stage Engine Delivery</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ares V Core Stage Booster</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ares V Earth Departure Stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ares V Earth Departure Stage Engine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**National Aeronautics and Space Administration**
Ares V remains the heavy-lift component of NASA's exploration architecture and a key component of "national strategy".

The upgraded RS-68 is crucial to the technical viability of Ares V and the only option for an affordable booster engine.