NASA’s Liquid Oxygen/Hydrocarbon (LOX/HC) Engines

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Space Launch System (SLS) Chief Engineer
NASA Marshall Space Flight Center

July 16, 2013
Powering the Future of Exploration
• **NASA systems**
  - RP-1 experience spans a significant period of Agency history
  - Strong heritage of hardware design, development, analysis and test exists within the agency
  - Marshall Space Flight Center (MSFC) has significant capabilities in supporting disciplines such as materials, manufacturing, and test

• **Industrial base strengthened through NASA programs and technology transfer**
  - History of partnering with industry in various capacities has further advanced the U.S. knowledge base
  - Transfer of key design codes, test and materials data, analytical results
  - Recent F-1 disassembly work, both at MSFC and at Aerojet Rocketdyne, ensures the next generation has an understanding of RP-1 propulsion
History of LOX/RP-1 Engine Development
MSFC Partnered with Industry

1955–1973
F-1
Gas Generator Cycle
Prime: Rocketdyne
Flew on Saturn V

F-1A
In development at the end of the program
Upgraded Turbomachinery

1996–2001
Fastrac (MC-1)
Gas Generator Cycle
Government Design
Hardware Prime: Summa
Vehicle Prime: Orbital
Engine was Fully Developed
Engine assembled into the X-34 vehicle but did not fly

2001–2004
TR107
Ox- Rich Stage Combustion
Prime: TRW
Engine to CoDR fidelity
Subscale (5k) Pintle Test at Purdue
250 k Preburner Built, not Tested

2001–2004
RS-84
Ox-rich Stage Combustion
Prime: Rocketdyne
Engine to IDR
(nearly CDR fidelity)
Significant subscale testing completed
<table>
<thead>
<tr>
<th>Engine</th>
<th>Tsl (Klb)</th>
<th>Tvac (Klb)</th>
<th>Isp (sl) (sec)</th>
<th>Isp (vac) (sec)</th>
<th>Pc (psia)</th>
<th>Wt (lbm)</th>
<th>T/W (sl/vac)</th>
<th>L (in)</th>
<th>MR</th>
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<tbody>
<tr>
<td>Fastrac</td>
<td>60</td>
<td>63.9</td>
<td>300</td>
<td>314</td>
<td>652</td>
<td>80</td>
<td>2.17</td>
<td>180</td>
<td>2.17</td>
</tr>
<tr>
<td>TR107</td>
<td>1,000</td>
<td>1,074</td>
<td>300</td>
<td>327</td>
<td>2,500</td>
<td>11,300</td>
<td>88 / 95</td>
<td>180</td>
<td>2.7</td>
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<tr>
<td>ORSC-RS84</td>
<td>1,050</td>
<td>1,155</td>
<td>305</td>
<td>335</td>
<td>2,700</td>
<td>15,925</td>
<td>65 / 73</td>
<td>168</td>
<td>2.7</td>
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<tr>
<td>F-1</td>
<td>1,522</td>
<td>1,748</td>
<td>265.4</td>
<td>304.1</td>
<td>982</td>
<td>18,616</td>
<td>65 / 73</td>
<td>220</td>
<td>2.27</td>
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</tbody>
</table>
History of LOX/RP-1 Propulsion
Unique Test Facilities Aid Industry

East Test Area
- Subscale and component level high-pressure testing of injectors, nozzles, pumps, thrust chambers
  - TS115, TS116

Materials Lab
- Failure investigation
- Comprehensive materials testing
- State of the art welding, brazing techniques
- Structured light
- Advanced manufacturing

North Test Area
- Unique, low-cost, quick-turnaround fluid flow tests
- Turbine, inducer, pump, and nozzle test facilities

Stennis Space Center
- LOX/RP-1 engine systems testing
- LOX/RP-1 large component testing
- Stage testing

Component Development Area
- Unique propulsion system component technology assessment
- Focused on valve, regulator, solenoid, and seal development
History of LOX/RP-1 Propulsion
Recent F-1 Disassembly

Prepares Government and Industry Workforce for SLS Advanced Booster NRA
## Studies & Activities Leading to the SLS Decision

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
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<tbody>
<tr>
<td>Review of Human Space Flight (HSF) Plans Committee (Augustine Panel)</td>
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<tr>
<td>Heavy Lift Launch Vehicle (HLLV) Study</td>
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<tr>
<td>Heavy Lift Propulsion Technologies Study (HLPT)</td>
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<td>Human Exploration Framework Team (HEFT) and HEFT II</td>
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<td>Broad Agency Announcements (BAA)</td>
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<td>NASA/U.S. Air Force (USAF) Common Engine Study</td>
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<tr>
<td>Heavy-Lift Vehicle (HLV) Analysis of Figures of Merit (FOM)</td>
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<td>Requirements Analysis Cycle (RAC) 1</td>
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<td>SLS Mission Concept Review (MCR)</td>
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<tr>
<td>Exploration Systems Development (ESD) SLS Analysis of Alternatives (AoA)</td>
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<tr>
<td>Agency Integrated Architecture Decision</td>
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<td>SLS Program Planning and Budget Execution for FY13 to Agency</td>
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<td>SLS Acquisition Strategy Meeting</td>
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<td>Independent Cost Assessment Report (Booz Allen Hamilton)</td>
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<tr>
<td>SLS Rolled out by NASA Administrator</td>
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Engineering and Business Analyses Validated SLS Architecture Selected by the Agency
The Congress passed and the President signed the National Aeronautics and Space Administration Authorization Act of 2010.

- Bipartisan support for human exploration beyond low-Earth orbit (LEO)

The Law authorizes:

- Extension of the International Space Station (ISS) until at least 2020
- Strong support for a commercial space transportation industry
- Development of Orion Multi-Purpose Crew Vehicle (MPCV) and heavy lift launch capabilities
- A “flexible path” approach to space exploration, opening up vast opportunities including near-Earth asteroids and Mars
- New space technology investments to increase the capabilities beyond Earth orbit (BEO)
The Space Launch System [will] be the backbone of its manned spaceflight program for decades. It [will] be the most powerful rocket in NASA’s history…and puts NASA on a more sustainable path to continue our tradition of innovative space exploration.

President Obama’s Accomplishments for NASA
May 22, 2012
SLS Driving Objectives

- **Safe**
  - Human-rated to provide safe and reliable systems
  - Protecting the public, NASA workforce, high-value equipment and property, and the environment from potential harm

- **Affordable**
  - Maximum use of common elements and existing assets, infrastructure, and workforce
  - Constrained budget environment
  - Competitive opportunities for affordability on-ramps

- **Sustainable**
  - Initial capability: 70 metric tons (t), 2017–2021
    - Serves as primary transportation for Orion and human exploration missions
  - Evolved capability: 105 t and 130 t, post-2021
    - Offers large volume for science missions and payloads
    - Reduces trip times to get science results faster
    - Minimizes risk of radiation exposure and orbital debris impacts

*Powerful, Versatile, Evolvable*
SLS Block Commonality

Orion, Multi-Purpose Crew Vehicle (MPCV- LMCO)

Interim Cryogenic Propulsion Stage (ICPS) (EELV 5m DCSS – Boeing/ULA)

Core Stage/Avionics (Boeing)

5-Segment Solid Rocket Booster (SRB) (ATK)

Core Stage Engines (RS-25) (Aerojet Rocketdyne)

Launch Abort System

Commonality of Payload Interfaces
- Mechanical
- Avionics
- Software

Upper Stage & Core Stage Commonality
- Same diameter (27.5 ft.) and basic design
- Manufacturing facilities, tooling, materials, & processes/practices
- Workforce
- Supply chain/industry base
- Transportation logistics
- Ground systems/launch infrastructure
- Propellants

Commonality of Core Stage

Commonality of Engines

Evolutionary Path to Future Capabilities
- Minimizes unique configurations
- Allows incremental development

Block 1
Initial Capability, 2017-21
70 metric ton Payload

Block 2 Capability
130 metric ton Payload

www.nasa.gov/sls
Most Capable U.S. Launch Vehicle

<table>
<thead>
<tr>
<th>Size</th>
<th>ULA Atlas V 551</th>
<th>SpaceX Falcon 9</th>
<th>ULA Delta IV H</th>
<th>NASA Space Shuttle</th>
<th>NASA Saturn V</th>
<th>NASA 70 t</th>
<th>NASA 130 t</th>
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</thead>
<tbody>
<tr>
<td>Volume (m^3)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Payload Mass (mT)</td>
<td></td>
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As of May 2, 2013
The Road to First Flight in 2017

<table>
<thead>
<tr>
<th>NASA Life Cycle Phases</th>
<th>Approval for Formulation</th>
<th>FORMULATION</th>
<th>Approval for Implementation</th>
<th>IMPLEMENTATION</th>
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<tr>
<td>Program Life Cycle Phases</td>
<td>Pre-Phase A: Concept Studies</td>
<td>Phase A: Concept &amp; Technology Development</td>
<td>Phase B: Preliminary Design &amp; Technology Completion</td>
<td>Phase C: Final Design &amp; Fabrication</td>
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<tr>
<td>Program Life Cycle Gates and Major Events</td>
<td>Key Decision Point A</td>
<td>KDP B</td>
<td>KDP C</td>
<td>KDP D</td>
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<tr>
<td>Human Space Flight Project Reviews</td>
<td>MCR</td>
<td>SRR/SDR</td>
<td>PDR</td>
<td>CDR</td>
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</table>

[A] monumental effort … has gone into this Program…. I don’t think anyone would have thought in September [2011] that this Program might be this far so fast.

LeRoy Cain, Chair
Standing Review Board
June 29, 2012

<table>
<thead>
<tr>
<th>CDR: Critical Design Review</th>
<th>MCR: Mission Concept Review</th>
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<tr>
<td>EM: Exploration Mission</td>
<td>PDR: Preliminary Design Review</td>
</tr>
<tr>
<td>EFT: Exploration Flight Test</td>
<td>SIR: System Integration Review</td>
</tr>
<tr>
<td>FRR: Flight Readiness Review</td>
<td>SDR: System Definition Review</td>
</tr>
<tr>
<td>KDP: Key Decision Point</td>
<td>SRR: System Requirements Review</td>
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