Propulsion Progress for NASA’s Space Launch System

Todd A. May, SLS Program Manager
Garry M. Lyles, SLS Chief Engineer
Alex S. Priskos, SLS Boosters Manager
Michael (Mike) H. Kynard, SLS Liquid Engines Manager

Space Launch System Program, Marshall Space Flight Center, AL 35812

Abstract

Leaders from NASA’s Space Launch System (SLS) will participate in a panel discussing the progress made on the program’s propulsion systems. The SLS will be the nation’s next human-rated heavy-lift vehicle for new missions beyond Earth’s orbit. With a first launch slated for 2017, the SLS Program is turning plans into progress, with the initial rocket being built in the U.S.A. today, engaging the aerospace workforce and infrastructure. Starting with an overview of the SLS mission and programmatic status, the discussion will then delve into progress on each of the primary SLS propulsion elements, including the boosters, core stage engines, upper stage engines, and stage hardware. Included will be a discussion of the 5-segment solid rocket motors (ATK), which are derived from Space Shuttle and Ares developments, as well as the RS-25 core stage engines from the Space Shuttle inventory and the J-2X upper stage enginetesting (Pratt & Whitney Rocketdyne). The panel will respond to audience questions about this important national capability for human and scientific space exploration missions.
Propulsion Progress for NASA’s Space Launch System

Todd A. May, Program Manager
Garry M. Lyles, Chief Engineer
Alex S. Priskos, Boosters Manager
Sheryl Kittredge, Liquid Engines Deputy Manager

July 2012
Todd May, Program Manager
NASA’s Vision and SLS Missions
“To reach for new heights...
and reveal the unknown so that what we do and learn
will benefit all humankind.”

- Extend and sustain human activities across the solar system.
- Expand scientific understanding of the Earth and the universe in which we live.

NASA 2011 Strategic Plan

SLS Launches in 2017

www.nasa.gov/sls
The Future of Exploration

“This expanded role for the private sector will free up more of NASA’s resources to do what NASA does best — tackle the most demanding technological challenges in space, including those of human space flight beyond low-Earth orbit.”

— John P. Holdren, Science and Technology Assistant to the President
The White House, May 22, 2012

“My desire is to work more closely with the human spaceflight program so we can take advantage of synergy. We think of the SLS as the human spaceflight program, but it could be hugely enabling for science.”

— John Grunsfeld, Associate Administrator
NASA Science Mission Directorate
Nature, Jan 19, 2012
SLS Benefits for Exploration

- Volume and mass capability
- Fewer origami-type payload designs needed to fit in the fairing
- High-energy orbit
- Shorter trip times

- Increased Mission Reliability and Confidence
- Increased Design Simplicity
- Less Expensive Mission Operations
- Less Risk

- Fewer deployments
- Fewer critical operations
- Increased lift capacity
- Increased payload margin

Safe, Affordable, Sustainable
Building a National Infrastructure Asset

For Beyond-Earth Orbit Exploration
Pursuing Affordability Solutions

- Lean, Integrated Teams with Accelerated Decision Making
- Robust Designs and Margins
- Risk-Informed Government Insight/Oversight Model
- Right-Sized Documentation and Standards
- Evolvable Development Approach
- Hardware Commonality

Sustainability through Life-Cycle Affordability

Focuses on the Data Content and Access to the Data
SLS Commonalities

70 ton Payload (Block 1)

130 ton Payload (Block 2)

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

RS-25 Core Stage Engines

www.nasa.gov/sls
5-Segment Solid Rocket Booster

Development Motor Test 3
Sep 8, 2011
ATK Promontory, UT
RS-25 Core Stage Engine
J-2X Upper Stage Engine
Partnering with Marshall and Michoud

- **Avionics Test-Bed**
  - May 2012

- **Multi-Purpose Crew Vehicle-to-Stage Adapter (MSA) for 2014 Launch of EFT-1**
  - June 2012

- **Systems Engineering & Integration**

- **Design Analysis Cycle 2**

- **Stages manufacturing demos and tooling preparation for friction stir welding**
  - April 2012

- **MSA designed and fabricated at Marshall**

www.nasa.gov/sls

8212 NEO.12
NASA’s Space Launch System

- Vital to NASA’s exploration strategy and the U.S. space agenda

- Key tenets: safety, affordability, and sustainability

- Partnerships with NASA Headquarters, Orion, Ground Operations, and other NASA Centers

- Prime contractors on board, work is in progress

- Competitive opportunities for innovations that affordably upgrade performance

- Completed System Requirements Review / System Definition Review

Launching in 2017

For More Info:
www.nasa.gov/sls
Garry Lyles, Chief Engineer
SLS Design and Development

www.nasa.gov/sls
A National Asset for Stakeholders and Partners

Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.
SLS Will Be the Most Capable Launch Vehicle

<table>
<thead>
<tr>
<th></th>
<th>Volume (ft³)</th>
<th>Payload (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Medium/Intermediate</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ULA Atlas V 551</td>
<td>7,840</td>
<td>40,780</td>
</tr>
<tr>
<td>SpaceX Falcon 9</td>
<td>5,156</td>
<td>23,050</td>
</tr>
<tr>
<td><strong>ULAs</strong></td>
<td></td>
<td></td>
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<tr>
<td>Delta IV H</td>
<td>7,133</td>
<td>49,736</td>
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<tr>
<td><strong>SpaceX</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Falcon 9 Heavy</td>
<td>5,156</td>
<td>55,000</td>
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<td><strong>NASA</strong></td>
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<td></td>
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<tr>
<td>Space Shuttle</td>
<td>10,559</td>
<td>22,560</td>
</tr>
<tr>
<td>Saturn V</td>
<td>18,434</td>
<td>53,070</td>
</tr>
<tr>
<td><strong>NASA SLS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>105 t</td>
<td>19,105</td>
<td>105,000</td>
</tr>
<tr>
<td>130 t</td>
<td>19,105</td>
<td>130,000</td>
</tr>
</tbody>
</table>

Retired
SLS Initial Capability

INITIAL CAPABILITY, 2017–21

70 t
321 ft.

Launch Abort System

Orion Multi-Purpose Crew Vehicle (MPCV)

Interim Cryogenic Propulsion Stage (ICPS)
- MPCV/Stage Adapter
- Launch Vehicle/Stage Adapter

Core Stage/Avionics (Boeing)

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

Core Stage Engines (RS-25) (PWR)

www.nasa.gov/sls
Initial Exploration Missions (EM)

EM-1 in 2017
- Un-crewed circumlunar flight – free return trajectory
- Mission duration ~7 days
- Demonstrate integrated spacecraft systems performance prior to crewed flight
- Demonstrate high speed entry (~11 km/s) and thermal protection system prior to crewed flight

EM-2 no later than 2021
- Crewed lunar orbit mission
- Mission duration 10–14 days
Ascent Mission Profile: SLS/Orion

**Launch**
- At Ignition: Time (sec) 0.0, Weight (lb) 5,795,338

**Core Stage Engine Cutoff**
- Time (sec) 475.2
- Maximum Acceleration

**Maximum Dynamic Pressure**
- Time (sec) 76.4
- Altitude (ft) 48,189
- Mach 1.84

**SRB Separation**
- Time (sec) 128.4
- Altitude (ft) 141,945
- Mach No. 4.33

**Maximum Boost Stage Axial Acceleration**
- Time (sec) 110.4
- Mach No. 3.9

**Payload Separation**
- Time (sec) MECO + 30 sec

**Gravity Turn**
- Places astronauts in heads-down position
- Uses Earth G to turn vehicle horizontal

**Tower Clear & Initiate Roll/Pitch Maneuver**
- 9 sec

**Core Stage Pacific Splashdown**
- 5579 sec (1.5 hrs)

**SRB Atlantic Splashdown**
- 331 sec (5.5 min)

**Core Stage Engine Cutoff**
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www.nasa.gov/sls
Exploration Flight Test-1 in 2014
MPCV Stage Adapter

First ring forging, ATI/Ladish, Cudahy, WI
April 2012

EFT-1 MPCV Stage Adapter
Design Review in March 2012
SLS Technical Communication Integration

◆ Accountability and Responsibility
  - Strong focus on technical leadership
  - Chief Engineer serves as lead designer
  - Chief Engineer and staff focused on technical integration
  - Organized to balance functional expertise and cross-functional integration
  - Early integration of production considerations
  - Entire organization focused on stakeholder value
SLS Lean Systems Engineering & Integration Model

- Benchmarked against diverse practices
  - Design-to-cost
  - Front-loaded product development
  - Using R&D and Knowledge Funnel approach to drive innovation and cost savings
  - Organized to balance functional expertise and cross-functional integration
  - Integrating suppliers in the product development system
  - Accelerated decision-making
  - Fewer control boards
  - Continuous Improvement
    - Contractor initiated processes to reduce contract value
    - Value-stream mapping
  - Supply Chain Management
    - Commonality
    - Simple targets and metrics for improving cost performance
  - Focus on early prototyping and testing

- Benchmarked companies: 3M, ATK, Boeing, HP, IDEO, Nucor, P&G, Raytheon, Toyota, and Commercial Crew providers

Focused on Safety, Affordability, and Sustainability
NASA’s Space Launch System

- **Vital to NASA’s exploration strategy and the Nation’s space agenda.**

- Key tenets: safety, affordability, and sustainability

- Design Analysis Cycle 2 in progress

- Trade space focused on delivering unsurpassed capability and capacity for national and international missions

- Using affordability as a key figure of merit, and development and operations costs in decision-making

- Refining engineering models and modes of operation

- Preliminary Design Review in 2013

*On Track for First Flight in 2017*
Boosters Overview

♦ **Block 1 Booster Configuration**
  - Two flights (2017 and 2021)
  - Utilizes existing hardware/contracts
    - ATK prime contractor
  - Heritage hardware/design
    - Forward structures
    - Metal cases
    - Aft skirt
    - Thrust Vector Control
  - Upgraded hardware/design
    - Expendable design
    - New avionics
    - Asbestos-free insulation
    - Five-segment solid rocket motor
      - Increased performance
      - Additional segment
      - Unique thrust-time profile

♦ **Block 1A/2 Booster Configuration**
  - Used in flights beyond 2021
  - DDT&E will be awarded by a competitive procurement.
  - Improved performance by either liquid or solid propulsion

♦ **This presentation focuses on the Block 1 booster design, development, test, and evaluation (DDT&E)**

70 ton Payload (Block 1)

130 ton Payload (Block 2)
Development Motor Test Status – Static Tests

DM-3 Static Test

DM-1 Nozzle post-fire inspection
Development Motor Test Status – Motor Performance

DM-3 Vacuum Thrust at Reference Conditions

DM-1 Static Test
Development Motor Test Status – Insulation

Layup process of PBI - NBR insulator

Post-test inspection of DM-1 insulator
Development Motor Test Status – Nozzle

DM-3 FNR post-test

DM-3 UT locations
Booster Avionics Testing

Avionics Flight Control Test-1

HPUC undergoing Qualification level Random Vibration testing at L-3/CE

ISC supporting Control Demonstration Test at MSFC

Isometric view of HPUC Line Unit (LRU)
Life Cycle Cost and Value Stream Mapping

◆ In 2008, NASA established a team to evaluate the design-to-cost (DTC) estimate and develop ways to significantly reduce production cost for the Ares I First Stage booster
  • Identified NASA’s culture of insight and oversight as a significant cost driver.
    – NASA/ATK typically maintain high levels of interface without restricting interaction points
  • NASA reduced the number of official avenues for contractor direction, also reducing ATK workforce burden

◆ Beginning in 2011, NASA and ATK began utilizing a value stream mapping (VSM) process to identify ways for streamlining/optimizing the manufacture and assembly of SLS boosters
  • Approximately 750 total changes
    – Includes 423 process improvements approved to eliminate source of waste
    – More than 400 moves eliminated
    – All Class I/IR and/or Type I *PC* changes require NASA ERB/ECB approval
      • Booster ERB/ECB has approved 114 process improvements to date
    – 46% cycle time improvement and reduce projected costs by millions of dollars, with no significant increased risk to the hardware, mission, and program
    – All major motor production areas have completed their respective VSMs
Advanced Booster and Engineering Demonstration and Risk Reduction

- Advanced Booster Engineering Demonstration and Risk Reduction
  - Acquisition will identify and mitigate risk at the Element and System Levels.
  - Target area risk reduction focusing on
    - Affordability
    - Performance
    - Reliability
  - Competition via NASA Research Announcement (NRA) was released February 2012
  - Expect the effort to begin at the beginning of FY13

- Advanced Booster Design, Development, Test, and Evaluation (DDT&E)
  - Scope: Follow-on procurement for DDT&E of a new booster
  - Date: RFP target is FY15
  - Capability: Evolved at 130 t
  - Contract: Full and Open Competition (Liquids or Solids) Advanced Booster Competitive Procurement
NASA’s Space Launch System
Boosters Element Summary

- Booster provides primary liftoff propulsion to the SLS vehicle
- Block 1 booster design is derived from and incorporates improvements over SSP RSRM
- SLS Booster has successfully completed component-level and significant major subsystem tests
- Over the coming years, several major milestones are planned for the SLS Booster Team
  - Booster Readiness Review: August 2012
  - Avionics Flight Control Test #2: September 2012
  - Booster Preliminary Design Review: Spring 2013
  - QM-1 static test: mid-2013
  - QM-2 static test: late-2014

Launching in 2017

For More Info:
www.nasa.gov/sls
Sheryl Kittredge, Liquid Engines
Deputy Manager
SLS Liquid Propulsion Element Status
# Core Stage Engine (RS-25)

<table>
<thead>
<tr>
<th>Core Stage Engine</th>
<th>Existing RS-25 Inventory</th>
<th>New Build RS-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propellant</td>
<td>LO2/LH2</td>
<td>LO2/LH2</td>
</tr>
<tr>
<td>Max power level</td>
<td>109% RPL</td>
<td>111% RPL</td>
</tr>
<tr>
<td>Throttle Range</td>
<td>65%-109% RPL</td>
<td>65%-111% RPL</td>
</tr>
<tr>
<td>Avg Thrust @ max power (vac)</td>
<td><strong>512,185</strong> lbs</td>
<td>521,700lbs</td>
</tr>
<tr>
<td>Min Isp @ max power (vac)</td>
<td>450.8</td>
<td>450.8</td>
</tr>
<tr>
<td>Engine Mass (each)</td>
<td>7,816</td>
<td>NTE 8,156</td>
</tr>
<tr>
<td>Nom, Range MR</td>
<td>6.043, 5.85-6.1</td>
<td>6.043, 5.85-6.1</td>
</tr>
<tr>
<td>Size</td>
<td>96&quot;x168&quot;</td>
<td>96&quot;x168&quot;</td>
</tr>
</tbody>
</table>

**RS-25 Power Level (PL) Terminology**
- 104.5% Nominal existing inventory flight certified PL
- 109.0% Max existing inventory flight certified PL
- 111.0% Max existing inventory ground test demonstrated PL

15 RS-25 engines - previously stored at KSC Engine shop - now housed at Building 9101 at SSC
**RS-25 Engine Inventory (At End of FY12)**

<table>
<thead>
<tr>
<th>Flight Engines</th>
<th>Dev Engines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembled and Ready for Test</td>
<td>Some Fab and Assembly Required</td>
</tr>
<tr>
<td>Acceptance Testing Required</td>
<td>0525</td>
</tr>
<tr>
<td>Some Fab and Assembly Required</td>
<td>0528</td>
</tr>
</tbody>
</table>

- Flight Engines:
  - 2044, 2045, 2047, 2048
  - 2050, 2051, 2052
  - 2054, 2056, 2057, 2058
  - 2059, 2060, 2061
  - 2062
  - 2063

- Dev Engines:
  - 0525
  - 0528
Upper Stage Engine J-2X

- Cycle: Gas Generator
- Thrust, vac (klbs): 294 (285K*)
- Isp, vac (sec): 448 (436*)min
- Pc (psia): 1,337
- MR: 5.5
- AR: 92 (59*)
- Weight (lbm): 5,450 max
- Secondary Mode MR: 4.5
- Secondary Mode PC: ~82%
- Restart: Yes
- Operational Starts: 8
- Operational Seconds: 2,600
- Length (in), Max: 185
- Exit Dia. (in), Max: 120

*With short nozzle extension*
J-2X Accomplishments – Engine 10001

Full Power Level in 4 Tests and Mission Duration in 7 Hot Fire Tests!

Test 1 July 7th - Chill
Test 2 July 14th - 1.9s, Ignition
Test 3 July 26th - 3.7s, 103% PL
Test 4 Aug 5th - 7.0s, 100% PL
Test 5 Aug 17th - 32.3s, 103% PL
Test 6 Sep 28th - 40.0s, 103% PL
Test 7 Oct 25th – 140.0s, 100% PL
Test 8 Nov 9th – 500.0s, 100% PL
## J-2X Engine Inventory
### Manufacturing and Assembly Status

<table>
<thead>
<tr>
<th>Assembly Complete and In Testing</th>
<th>Ready to Assemble</th>
<th>In Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="E10001" /></td>
<td><img src="image2" alt="E10002" /></td>
<td><img src="image3" alt="E10004" /></td>
</tr>
<tr>
<td></td>
<td><img src="image4" alt="E10003" /></td>
<td><img src="image5" alt="E10005" /></td>
</tr>
</tbody>
</table>
RS-25 Engine Controller Overview

RS-25 Engine Controller

SSMEC

Universal Engine Controller

J-2X ECU

RS-25 CSEC (Core Stage Engine Controller)
Selective Laser Melting Road to Flight

Component Development

Built and hot-fire tested J-2X gas generator discharge duct

J-2X fuel turbine exhaust duct maintenance port plug is being built for engine hot-fire testing

Successfully built RS-25 internally tied bistra

Will build and water flow test RS-25 POGO Z-baffle.

Plans in work to green run and certify SLM POGO Z-baffle for use on RS-25.

Material and Process Development

Created draft SLM Engineering and Quality Guidelines document

Developing inspection techniques

Mechanical testing of material samples, developing materials verification matrix

Procurement of SLM machine for MSFC Materials Lab.

Working with Army and Air Force on material development

Build flight rationale

Fly SLM components in 2017.

Additional MSFC Activities

Participation in 3 separate proposals for Air Force Broad Agency announcement, pilot Additive Mfg Innovation Institute

Engineering Development:
• Unique tooling fabrication
• Injector elements and various other components for MSFC component test bed
• Turbopump components
• Small thruster development

www.nasa.gov/sls 8229_JPC.42
Structured Light

RS25 Mixer

Part to be scanned

Scanning

Raw Scan Data

Analysis of Data, CAD Comparison
SLS Structured Light Examples

- Engine Interface Adjustment
- J-2X Extension
- J-2X Engine Integration
- J-2X Duct Alignment
- ASI Erosion Mapping
- RS25 Powerhead Reverse Engineering

www.nasa.gov/sls
NASA’s Space Launch System
Liquid Engines Element Summary

- Four ship sets of RS-25 engines on hand to support early SLS flights
- J-2X testing a year away from completion
- Working on controller hardware to integrate RS-25 with newer systems
- Investigating new technologies to improve testing and lower the cost of future units

Launching in 2017

For More Info:
www.nasa.gov/sls
Somewhere, something incredible is waiting to be known.
— Carl Sagan
BACKUP
Structured Light Compared to Traditional

Scanning of SLS engine components has demonstrated a 6.5X time savings, which is consistent with the non-aerospace experience.

<table>
<thead>
<tr>
<th>Component</th>
<th>Traditional</th>
<th>Structured Light</th>
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</thead>
<tbody>
<tr>
<td>J-2X Stub 2</td>
<td>60</td>
<td>7</td>
</tr>
<tr>
<td>J-2X Nozzle 10003</td>
<td>75</td>
<td>30</td>
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<tr>
<td>Stealth Coating Aplication</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>CMM Sphere</td>
<td>16</td>
<td>1.5 0.4</td>
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<tr>
<td>Plastic Air Box</td>
<td>121</td>
<td>19</td>
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<tr>
<td>Plastic Intake Manifold</td>
<td>82</td>
<td>16</td>
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<tr>
<td>BMW Door (Prod)</td>
<td>4.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Phone Shell - First Article</td>
<td>16</td>
<td>1.5</td>
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</table>