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
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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 engine now in testing (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

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

- Fewer deployments
- Fewer critical operations
- High-energy orbit
- Shorter trip times
- Volume and mass capability
- Fewer origami-type payload designs needed to fit in the fairing
- Increased lift capacity
- Increased payload margin

Safe, Affordable, Sustainable
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
SLS Commonalities

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

70 ton Payload (Block 1)

130 ton Payload (Block 2)

RS-25 Core Stage Engines
5-Segment Solid Rocket Booster
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

MSA designed and fabricated at Marshall

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

Preliminary Design Review 2013
Garry Lyles, Chief Engineer

SLS Design and Development
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.

**Planetary Exploration**
- Mars
- Solar System

**Exploring Other Worlds**
- Low-Gravity Bodies
- Full-Capability Near-Earth Asteroid Missions
- Phobos / Deimos

**Into the Solar System**
- Interplanetary Space
- Initial Near-Earth Asteroid Missions
- Lunar Surface

**Extending Reach Beyond LEO**
- Cis-Lunar Space
- Geostationary Orbit
- High-Earth Orbit
- Lunar Flyby & Orbit

**Initial Exploration Missions**
- International Space Station
- Space Launch System
- Orion Multi-Purpose Crew Vehicle
- Ground Systems Development & Operations
- Commercial Spaceflight Development

**SLS — Going Beyond Earth’s Orbit**

ISS: 286 mi / 460 km

Mars: 34,600,000 mi / 55,700,000 km

Moon: 238,855 mi / 384,400 km
**SLS Will Be the Most Capable Launch Vehicle**

<table>
<thead>
<tr>
<th></th>
<th>Medium/Intermediate</th>
<th>Heavy</th>
<th>Super Heavy</th>
</tr>
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<tbody>
<tr>
<td>Rocket</td>
<td>ULA Atlas V 551</td>
<td>SpaceX Falcon 9</td>
<td>NASA SLS 105 t</td>
</tr>
<tr>
<td></td>
<td>ULA Delta IV H</td>
<td>SpaceX Falcon 9</td>
<td>NASA SLS 105 t</td>
</tr>
<tr>
<td></td>
<td>NASA Space Shuttle</td>
<td>NASA Saturn V</td>
<td>130 t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70 t</td>
<td>19,105</td>
</tr>
<tr>
<td></td>
<td></td>
<td>130 t</td>
<td>19,105</td>
</tr>
<tr>
<td></td>
<td></td>
<td>130 t</td>
<td>19,105</td>
</tr>
<tr>
<td>Volume</td>
<td>ft^3</td>
<td>ft^3</td>
<td>ft^3</td>
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<tr>
<td>(m^3)</td>
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<td>5.156</td>
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<tr>
<td></td>
<td>222</td>
<td>146</td>
<td>19,105</td>
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<tr>
<td>Payload</td>
<td>lbs</td>
<td>lbs</td>
<td>lbs</td>
</tr>
<tr>
<td>(kg)</td>
<td>40,780</td>
<td>23,050</td>
<td>231,485</td>
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<tr>
<td></td>
<td>22,560</td>
<td>105,000</td>
<td>286,601</td>
</tr>
<tr>
<td></td>
<td>22,560</td>
<td>105,000</td>
<td>286,601</td>
</tr>
</tbody>
</table>
SLS Initial Capability

INITIAL CAPABILITY, 2017–21

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)

Launch Abort System

70 t
321 ft.
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

Maximum Dynamic Pressure
Time (sec) 76.4
Altitude (ft) 48,189
Mach No. 1.84

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

Liftoff + 0.6 sec
Time (sec) 0.6

Payload Separation
Time (sec) MECO + 30 sec

SRB Atlantic Splashdown
331 sec (5.5 min)

Core Stage Engine Cutoff
Time (sec) 475.2
Maximum Acceleration

LAS Jettison
Time (sec) 158.4
Altitude (ft) 193,530
Mach No. 4.9

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

Gravity Turn minimizes aero loads on vehicle and uses Earth G to turn vehicle horizontal
Roll Maneuver places astronauts in heads-down position

Tower Clear & Initiate Roll/Pitch Maneuver 9 sec

Core Stage Pacific Splashdown 5579 sec (1.5 hrs)

Core Stage Engine Cutoff
Time (sec) 475.2
Maximum Acceleration

(Not To Scale)
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
Alex Priskos, Boosters Manager

SLS Booster Status
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)**
Development Motor Test Status – Static Tests

DM-3 Static Test

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

DM-1 Static Test

DM-3 Vacuum Thrust at Reference Conditions

www.nasa.gov/sls 8229 JPC.28
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

ISC supporting Control Demonstration Test at MSFC

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

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)

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

<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>512,185 lbs</td>
<td>521,700 lbs</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>

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

<table>
<thead>
<tr>
<th>Assembled and Ready for Test</th>
<th>Acceptance Testing Required</th>
<th>Some Fab and Assembly Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>2044 2045 2047 2048</td>
<td>2062</td>
<td>2063</td>
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<tr>
<td>2050 2051 2052</td>
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<td>2054 2056 2057 2058</td>
<td></td>
<td></td>
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<tr>
<td>2059 2060 2061</td>
<td></td>
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</tbody>
</table>

### Dev Engines

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Some Fab and Assembly Required</td>
</tr>
<tr>
<td>0525 0528</td>
</tr>
</tbody>
</table>
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.png" alt="Image" /> E10001</td>
<td><img src="image2.png" alt="Image" /> E10002</td>
<td><img src="image3.png" alt="Image" /> E10004</td>
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<tr>
<td><img src="image4.png" alt="Image" /> E10003</td>
<td></td>
<td><img src="image5.png" alt="Image" /> E10005</td>
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</table>

www.nasa.gov/sls 8229_JPC.40
RS-25 Engine Controller Overview

RS-25 Engine Controller

SSMEC

Universal Engine Controller

RS-25 CSEC (Core Stage Engine Controller)

J-2X ECU
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

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

Build flight rationale
Fly SLM components in 2017.

Activity Completed
Activity in work
Structured Light

RS25 Mixer

Part to be scanned

Scanning

Raw Scan Data

Analysis of Data, CAD Comparison
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.