Space Launch System
The Future of Exploration

Sharon Cobb, Ph.D., Assistant Program Manager
Space Launch System
NASA Marshall Space Flight Center
B.S., M.S., Materials Engineering, University of Alabama in Birmingham

November 7, 2013
A Deeper Purpose, A Bolder Mission

“To reach for new heights…

and reveal the unknown so that what we do and learn will benefit all humankind.”
The Next Great Ship

Ships of exploration opened the paths that became today’s trade routes.
Bigger Rocket = Unrivaled Mass, Unrivaled Volume

Enables missions no other rocket can perform.
Orion: Carrying astronauts into deep space

RS-25 Engines: 16 Space Shuttle engines are already in inventory

Solid Rocket Boosters: Built on Space Shuttle hardware; more powerful for a new era of exploration

Core Stage: Newly developed for SLS, the Core Stage towers more than 200 feet tall

Interim Cryogenic Propulsion Stage: Based on the Delta IV Heavy upper stage; the power to leave Earth
A National Effort

224 Subcontracts in 30 States are advancing technology and innovation.
NASA’s Space Launch System

Launching Soon.
Building Today.
SLS is the first step in the journey to Mars.

Going to Mars will be difficult. SLS provides the power that it takes.
Space Launch System
Core Stage

Michelle Taylor, SLS Engineer
Boeing Corporation
B.S., Electrical Engineering; M.S., Aerospace Engineering
University of Alabama

November 7, 2013
Core Stage & Avionics

NASA Marshall Space Flight Center (MSFC) Integrates SLS
Core Stage Major Structural Elements

FWD Skirt: 1 barrel, 8 welded panels, 2 welded rings

Intertank: Bolted cylinder

LH2 Tank: 5 barrels, 40 welded panels, 2 domes, 2 welded rings

LOX Tank: 2 barrels, 16 welded panels, 2 domes, 2 welded rings

Engine Section: 1 barrel, 8 welded panels, 2 welded rings
Vertical Weld Center (VWC)

VWC Dimensions

- 41 feet tall
- 40 feet wide
- 50 feet long
- Weight –165.5 tons (not including production hardware)

VWC Complete - Tool In Use
First Tank Barrel at MAF Vertical Weld Center
Enhanced Robotic Weld Tool (ERWT)

- Welds twelve gore panels together to form gore section
- Welds dome cap to top and ring to bottom of gore section to create complete dome

- The Circumferential Dome Weld Tool (CDWT) welds gore dome assemblies, rings and dome caps together to make dome assemblies
Segmented Ring Tool (SRT)

- Welds six ring segments to form one 8.4 meter ring
- Y-Rings connect tanks domes and barrels
- L-Rings connect dry structure barrels
Space Launch System
Rocket Engine Technology

Mike Kynard, Manager
SLS Liquid Engines Element
NASA Marshall Space Flight Center

November 7, 2013
RS-25
• The Workhorse of SLS Core Stage

RS-25 Single Engine Test on A1 Test Stand at Stennis Space Center

<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%</td>
<td>111%</td>
</tr>
<tr>
<td>Throttle Range</td>
<td>65%–109%</td>
<td>65%–111%</td>
</tr>
<tr>
<td>Avg Thrust @ max Pwr (vac)</td>
<td>512,185lbs</td>
<td>521,700lbs</td>
</tr>
<tr>
<td>Min Isp @ max Pwr (vac)</td>
<td>450.8 (452 Avg)</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 Size</td>
<td>6.043, 5.85-6.1</td>
<td>6.043, 5.85-6.1</td>
</tr>
<tr>
<td></td>
<td>96” x 168”</td>
<td>96” x 168”</td>
</tr>
</tbody>
</table>

RS-25 as the Space Shuttle Main Engine
• 3171 Total Starts
• 1,095,679 Total Seconds
• 135 flights – 100% mission success
• Reusable – Designed for 55 starts and 27,000 seconds
• First Test – 1975, Last Flight – 2011
**J-2X**

- **Upper Stage Engine for Evolved Vehicle**

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**Gimbal Test for J-2X**

On A1 Test Stand at Stennis Space Center

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### Upper Stage Engine

<table>
<thead>
<tr>
<th>Feature</th>
<th>J-2X</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Propellant</strong></td>
<td>LO2/LH2</td>
</tr>
<tr>
<td><strong>General Attributes</strong></td>
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</tr>
<tr>
<td>Max power level</td>
<td>100.0%</td>
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<tr>
<td>Thrust (vac)</td>
<td>294,000 lbf</td>
</tr>
<tr>
<td>Min Isp (vac)</td>
<td>448 seconds</td>
</tr>
<tr>
<td>Size</td>
<td>92” X 131”</td>
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<tr>
<td>Engine Mass</td>
<td>5,400 lbm</td>
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<tr>
<td>Mixture Ratio</td>
<td>5.5</td>
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<tr>
<td>Secondary Power Level</td>
<td>~82%</td>
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</tbody>
</table>

**Key Baseline Features**

- Short nozzle implemented (285k, 435s)
  - (Capable of 294K thrust and 448s)
- Re-startable
J-2X Development

System Testing

Powerpack 2
- 13 tests
  - Performance characterization of turbopumps, inlet ducts, and turbine bypass system
  - 6177 seconds total
    - Includes 1350 second test - longest test on A1 test stand

Engine 10001
- 21 tests
  - The first 10 tests performance characterization at sea level
  - Next 11 tests performance characterization with stub nozzle extension at simulated altitude
    - 2718 seconds total

Engine 10002
- 6 tests on A2 test stand
  - Engine-to-engine performance repeatability characterization with stub nozzle at simulated altitude
- 7 tests on A1 test stand
  - Gimbal testing at sea level
    - 5201 seconds total to date

14,096 total seconds
Structured Light Introduced to Sub-tier Vendors to modify tube dies to integrate supply chain (i.e. reduce turn around time for nozzle assembly)

Structured Light Scanning

Training and Implementing as a new technique for Rocketdyne Personnel

Reducing difficult measurements with scanning to help reduce performance uncertainty (throat and exit areas)

Implementing > 5:1 time savings.

Completing study to advance structured light as a quality acceptance tool.

Developing new optical techniques to augment traditional engine measurements

Structured Light Used to Generate Machining Code and Match Machine at PWR

Reducing the Development Cycle for Hardware
Technology
We’re Developing
•
Structured Light
Technology We’re Developing

- Selective Laser Melting
Technology We’re Developing

- Selective Laser Melting
**Engine Controller Unit (ECU)**

- **ECU function**
  - Controls thrust and mixture ratio
    - Open and closed loop
  - Continuously monitors engine health
  - Provides electric power to control elements, sensors, and effectors
  - Accepts commands from and reports data to vehicle computers

- **Challenge:** Heritage controller incompatible with new vehicle

- **Solutions**
  - Design new controller rather than adapt old
  - Leverage J-2X design for “universal controller”
Engine Controller Unit (ECU) (Continued)

Basic design supports RS-25 and J-2X
Roadmap to Improved RS-25

• Leverages Nation’s wealth of propulsion experience
• Maintain 100% mission success
• Introduce high maturity affordability enhancements
• Sustainable design, processes and supply chain
• Evolve into SLS to meet future mission needs

Delivery of affordable RS-25 engines is key to SLS success. J-2X represents the current state of NASA/AR capability to affordably design, develop, test, evaluate, and manage human-rated flight-qualified liquid rocket engines.
Space Launch System
Systems Engineering & Integration

Garry Lyles, Chief Engineer
SLS Program Office
B.A. in Mechanical Engineering, University of Alabama
Class of 2010 Distinguished Engineering Fellows

November 7, 2013
"We're going to get this country — and the world — exploring beyond low-Earth orbit very shortly.”

— Dan Dumbacher
Deputy Associate Administrator
Exploration Mission Directorate
70 Metric Ton Expanded View

Initial Capability Builds on Heritage Hardware
## SLS Development Schedule

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
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<td>MCR</td>
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<td></td>
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<td>✔️</td>
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<td>PLAR</td>
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<td>✔️</td>
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</table>

### Program Progress

- **2011**: SLS Design Chosen.
- **2012**: Engines Delivered to Inventory.
- **2013**: Manufacturing Tooling Installed.
- **2014**: Orion Flight Test.
- **2015**: Main Engine Test-Firing.
- **2016**: Core Stage Structure Testing.
- **2017**: Vehicle Stacking at KSC.

**Concept Studies**
- SLS Design Chosen
- Engines Delivered to Inventory
- Manufacturing Tooling Installed

**Concept & Technology Development**
- Wind Tunnel Testing
- Production of First New Flight Hardware

**Preliminary Design & Technology Completion**
- Main Engine Test-Firing
- ICPS Production Begins

**Final Design & Fabrication**
- Core Stage Assembly
- Booster Test-Firings

**System Assembly, Integration & Test, Launch & Checkout**
- Core Stage Test-Firing
- Booster Assembly at KSC
- First Flight

Legend:
- MCR: Mission Concept Review
- CDR: Critical Design Review
- SRR: System Requirements Review
- SIR: System Integration Review
- SDR: System Definition Review
- FRR: Flight Readiness Review
- PDR: Preliminary Design Review
- PLAR: Post-Launch Assess. Review
Accountability and Responsibility

Strong focus on leadership at all levels
Organized to balance functional expertise and cross-functional integration
Chief Safety Officer and staff provide guidance, analysis, and oversight/insight
Chief Engineer serves as lead designer, with staff focused on technical integration
Early integration of production considerations
Entire organization focused on stakeholder value
Top Technical Issues

- Loads and Environments
  - ICPS Engine/Actuator loads
  - Predicted Core Stage acceleration
  - Booster forward skirt
  - MPCV designed to Ares loads
  - Updated acoustic environments

- Performance Threats
  - Propulsion Performance
    - Mass Growth
    - Loads
  - Core Stage Engine
  - BSM Cover
  - Core Stage Booster Separation
  - FTG Pyro Delay

- Interfaces
  - Core Stage Engine
  - FTG Pyro Delay
  - BSM Cover
  - Core Stage Booster Separation

DAC-3 Touches Majority of Open Issues
Meeting Our Commitments & Exceeding Expectations

Engines
Tested selective laser melted part on J-2X at Stennis Space Center (March 2013)

Boosters
Conducted Thrust Vector Flight Control Test at ATK in Promontory, UT (Jan 2013)

Core Stage
Transferred Core Stage test panels to Michoud Assembly Facility (MAF) in New Orleans (Spring 2013)

On Course for First Flight In 2017

Spaceship & Payload Integration
Conducted fit-check of the Multi-Purpose Crew Vehicle Stage Adapter at the Marshall Space Flight Center for 2014 Exploration Flight Test (June 2013)

Advanced Development
Conducted F-1 engine hot-fire testing at Marshall (Jan 2013)

Systems Engineering & Integration
Tested buffet model in Langley Research Center’s Transonic Dynamics Wind Tunnel (Jan 2013)

"Awesome...huge step...stay focused and keep designing and building. December 2017 is closer than we think.

—William Gerstenmaier, Human Exploration and Operations Director, July 31, 2013
Islands in Our Ocean

- Earth-Sun Libration Points
  - Serviceable Large Diameter Telescopes
- Asteroids
  - Human missions
  - Robotic missions with sample return
- Mars, Phobos, Deimos
  - Human missions
  - Single-launch robotic sample return
- Deep Space/Planetary
  - Robotic sample return missions
  - Reduced flight time (years)
- Earth-Moon Libration Points
  - Way station
- Commercial Space Stations
  - Large diameter
  - Single launch
- Moon
  - Large-scale robotic precursor missions
  - Human settlement with resource utilization

www.nasa.gov/sls
Powering the Future of Exploration

Aerospace Engineering & Mechanics
Chemical & Biological Engineering
Computer Science
Mechanical Engineering

Civil, Construction & Environmental Engineering
Electrical & Computer Engineering
Metallurgical & Materials Engineering
“Man cannot discover new oceans unless he has the courage to lose sight of the shore.”

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