

# Propulsion Progress for NASA's Space Launch System

Todd A. May, SLS Program Manager

Garry M. Lyles, SLS Chief Engineer

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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

A composite image of the solar system. In the upper left, a bright yellow Sun glows. To its right, Earth is shown with blue oceans and white clouds, with the Moon in a crescent phase nearby. Further right, Mars is depicted in shades of orange and red, with a crescent moon. The foreground is filled with numerous brown, rocky asteroids of various sizes. A small satellite with solar panels is visible in the middle ground between Earth and Mars. The background is a deep blue space filled with stars.

**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.”

National Aeronautics and  
Space Administration



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

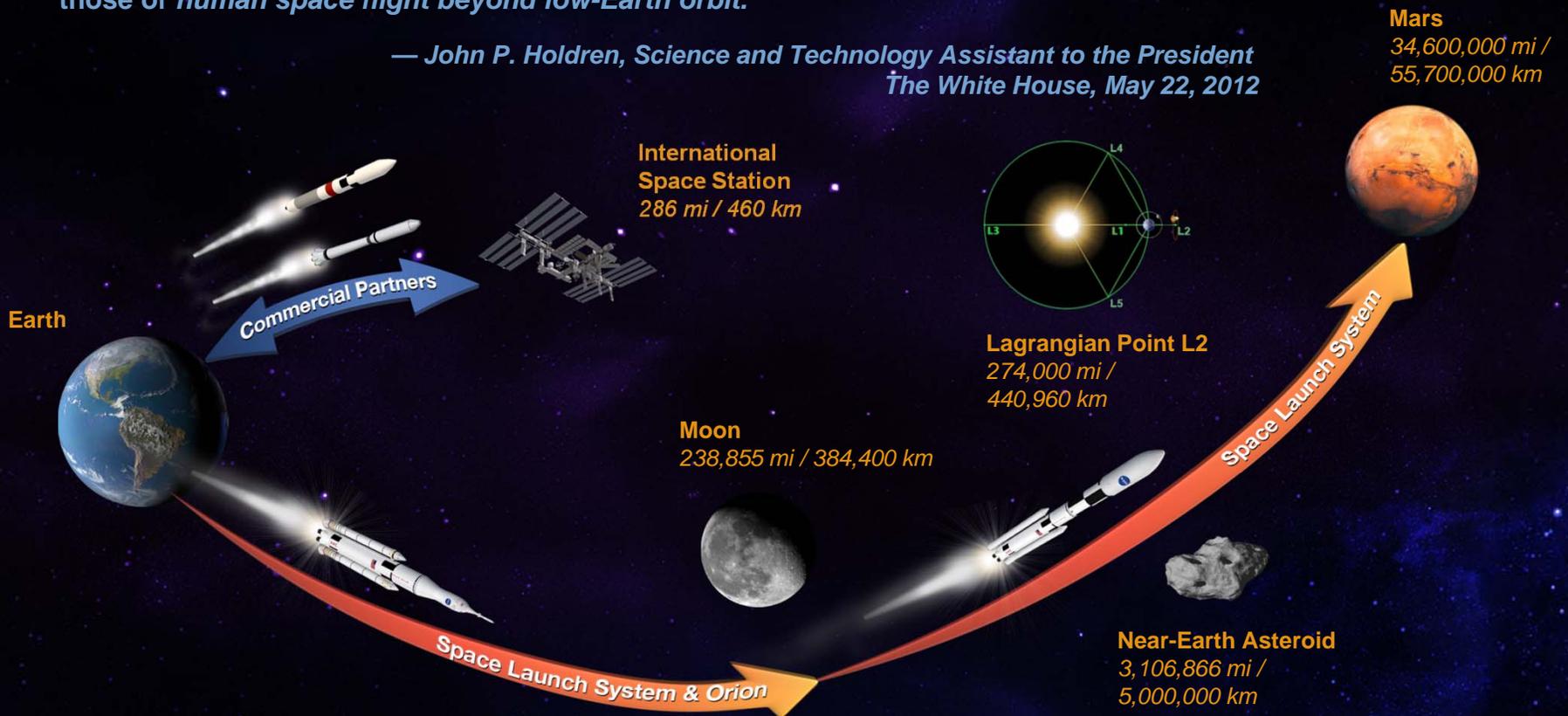
*NASA 2011 Strategic Plan*

*SLS Launches in 2017*

# 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



Moon



Near-Earth Asteroid



Mars



Jupiter



Saturn



Lagrange Points

- ◆ Volume and mass capability
- ◆ Fewer origami-type payload designs needed to fit in the fairing

- ◆ High-energy orbit
- ◆ Shorter trip times

Increased Design Simplicity

Less Expensive Mission Operations

Increased Mission Reliability and Confidence

Less Risk

- ◆ Fewer deployments
- ◆ Fewer critical operations

- ◆ Increased lift capacity
- ◆ Increased payload margin

**Safe, Affordable, Sustainable**

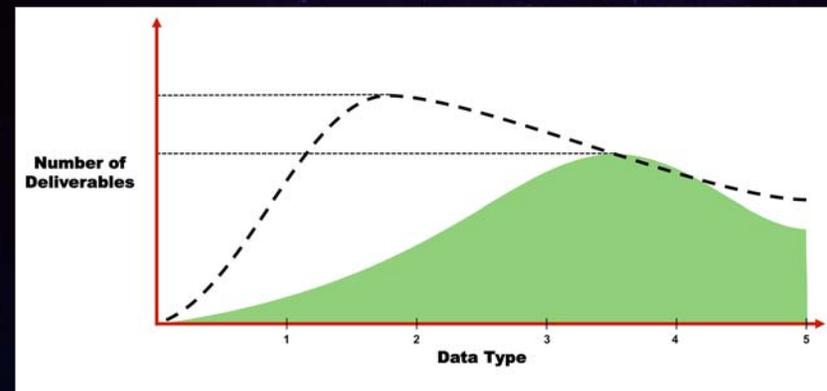
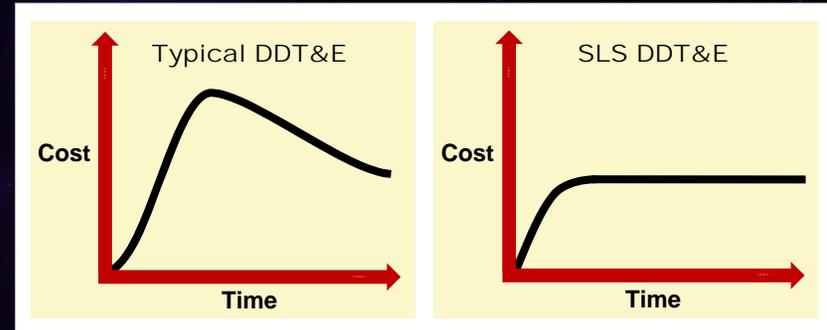
# Building a National Infrastructure Asset



*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



*Focuses on the Data Content and Access to the Data*

*Sustainability through Life-Cycle Affordability*

# SLS Commonalities

**70 ton Payload  
(Block 1)**



**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

**130 ton Payload  
(Block 2)**



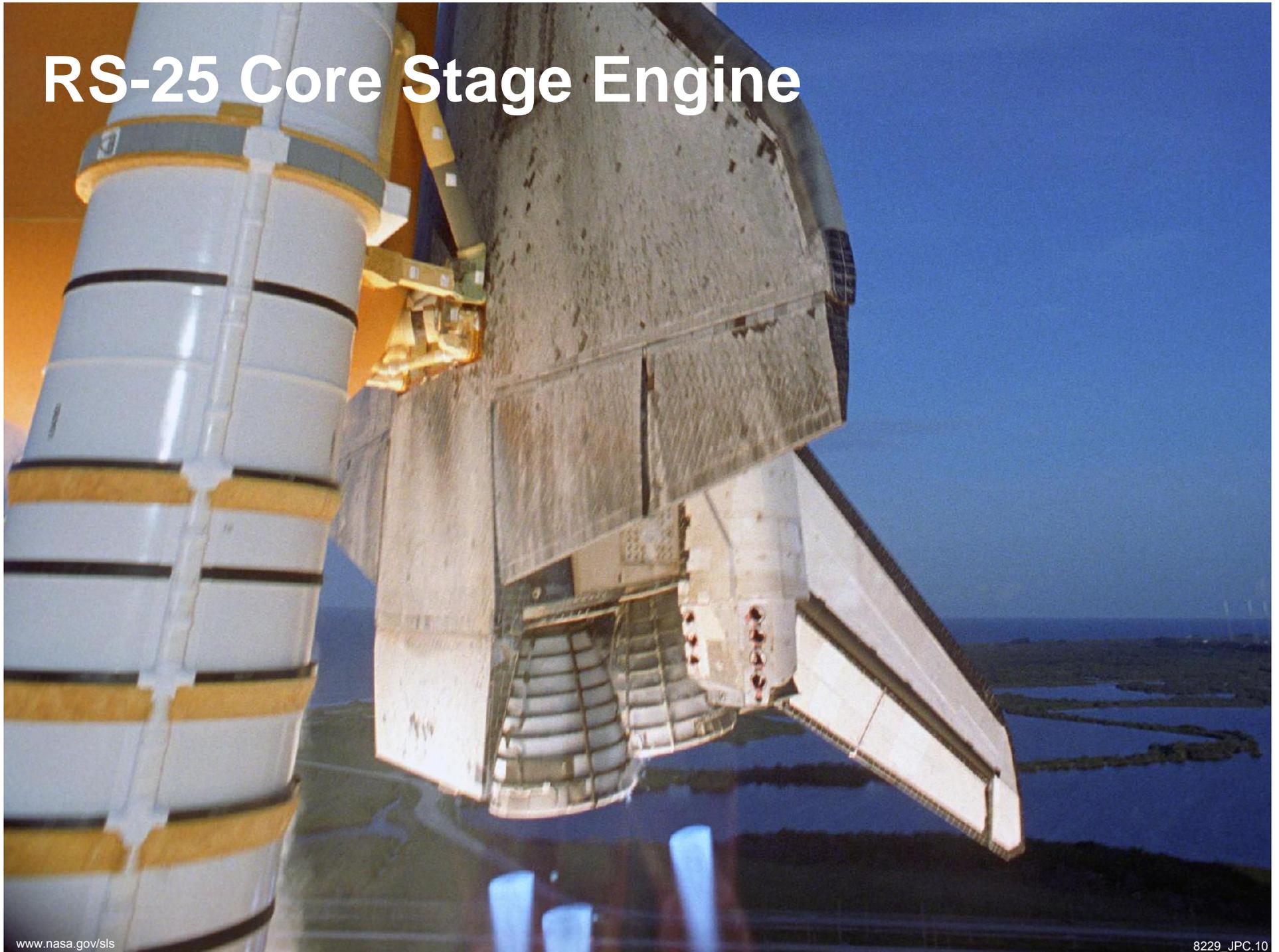
**RS-25 Core Stage Engines**

# 5-Segment Solid Rocket Booster

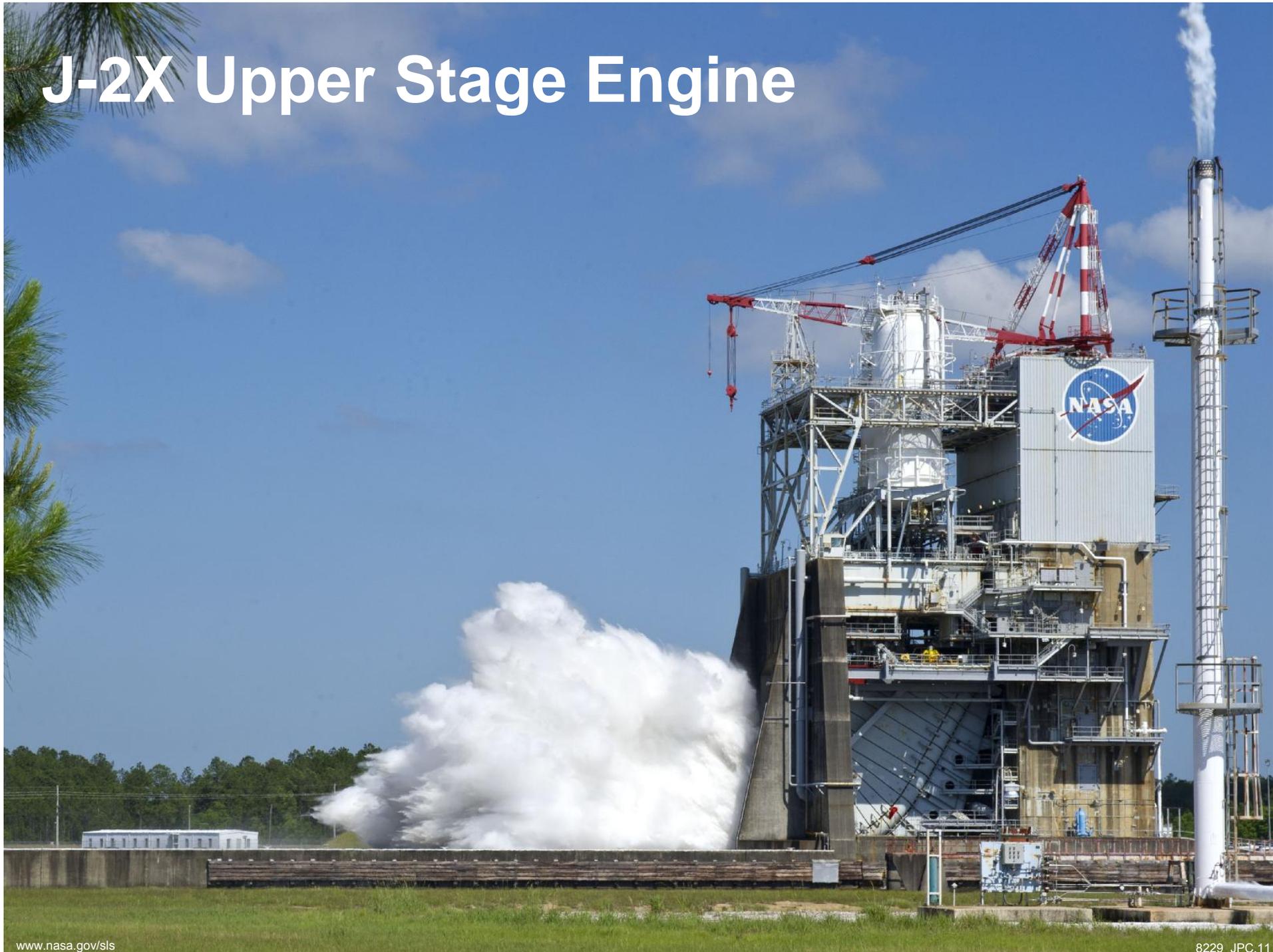


Development Motor Test 3  
Sep 8, 2011  
ATK Promontory, UT

# RS-25 Core Stage Engine



# J-2X Upper Stage Engine

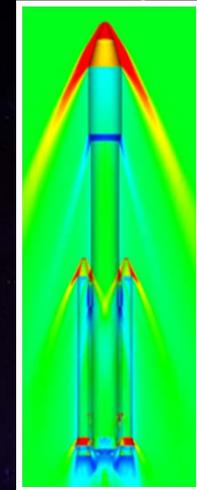


# Partnering with Marshall and Michoud



- ◆ Avionics Test-Bed  
May 2012

- ◆ Systems Engineering & Integration
- ◆ Design Analysis Cycle 2



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

- ◆ MSA designed and fabricated at Marshall



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



# 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

*Preliminary Design Review 2013*



**Launching in 2017**

*For More Info:*  
[www.nasa.gov/sls](http://www.nasa.gov/sls)



A composite image of space. In the top left, a bright yellow sun glows. To its right, Earth is shown with blue oceans and white clouds. Further right is a small grey moon. In the center-right, Mars is depicted with its characteristic reddish-orange surface and dark markings. To the right of Mars is another grey moon. The bottom half of the image is filled with numerous brown, rocky asteroids of various sizes. A small satellite with solar panels is visible in the middle ground between Earth and Mars. The background is a deep blue space filled with stars.

**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.

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

## 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

Moon: 238,855 mi / 384,400 km

ISS: 286 mi / 460 km

Surface Capabilities Needed

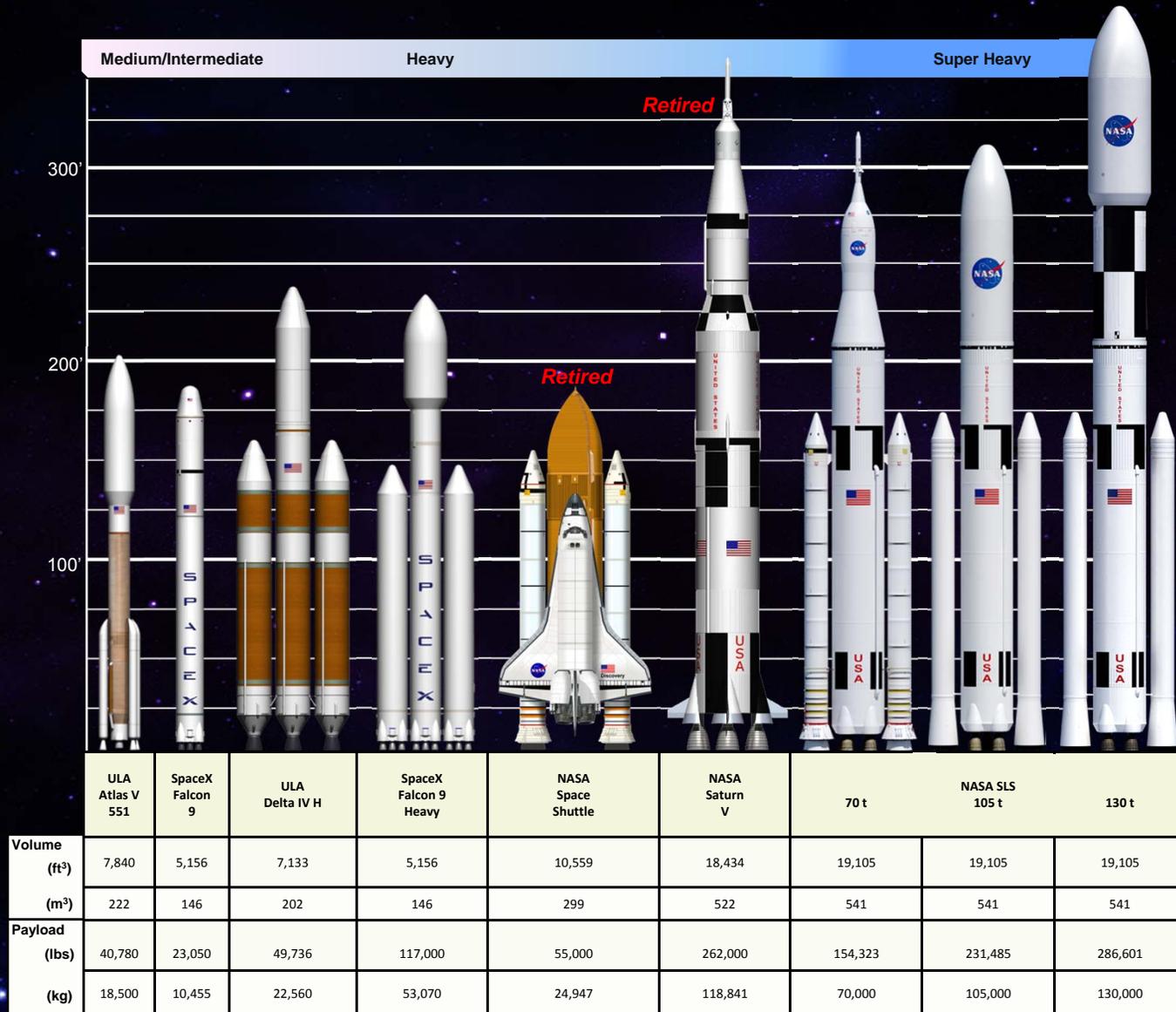
Advanced Propulsion Needed

High Thrust In-Space Propulsion Needed

Long Duration Habitat Needed

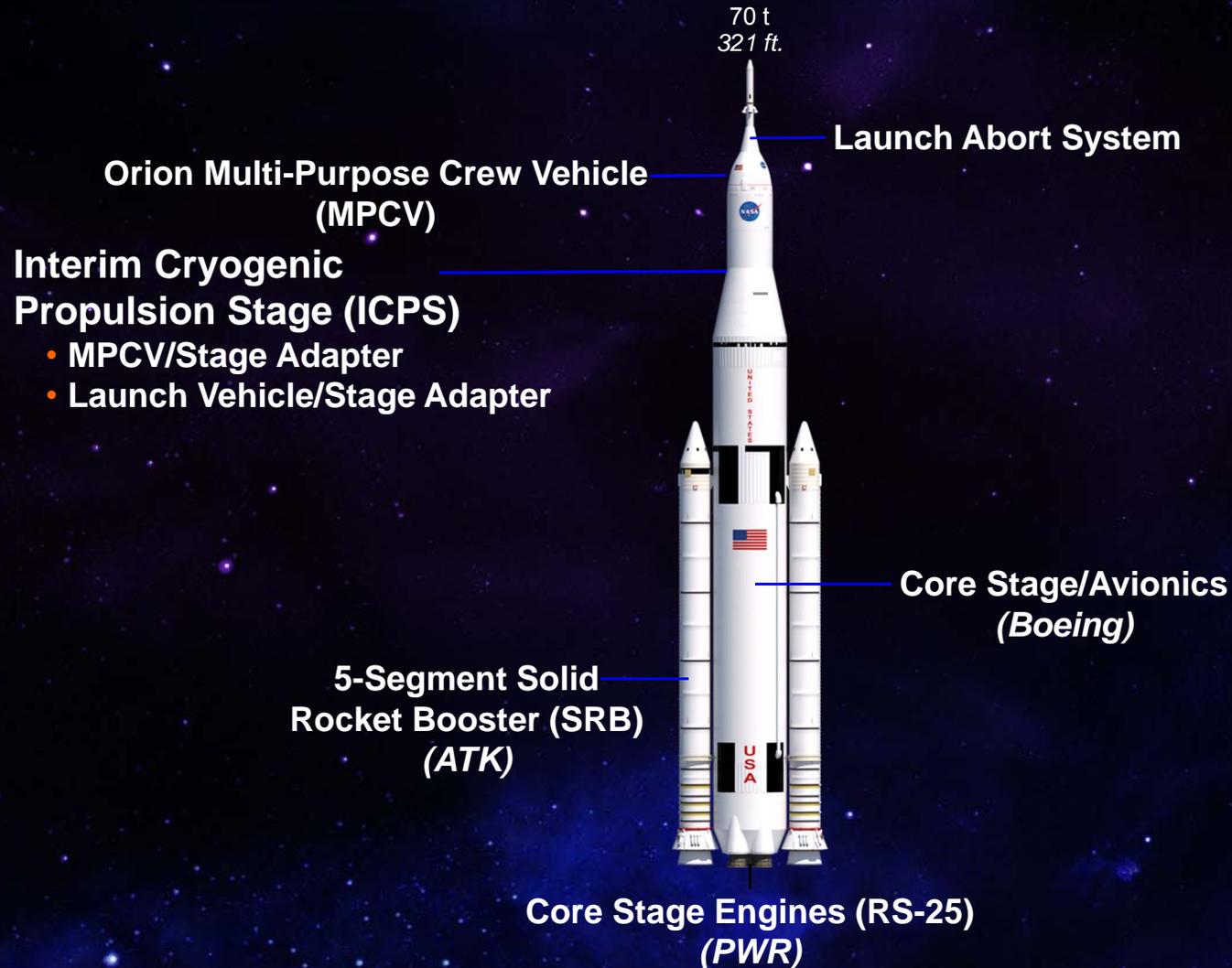
# SLS — Going Beyond Earth's Orbit

# SLS Will Be the Most Capable Launch Vehicle



# SLS Initial Capability

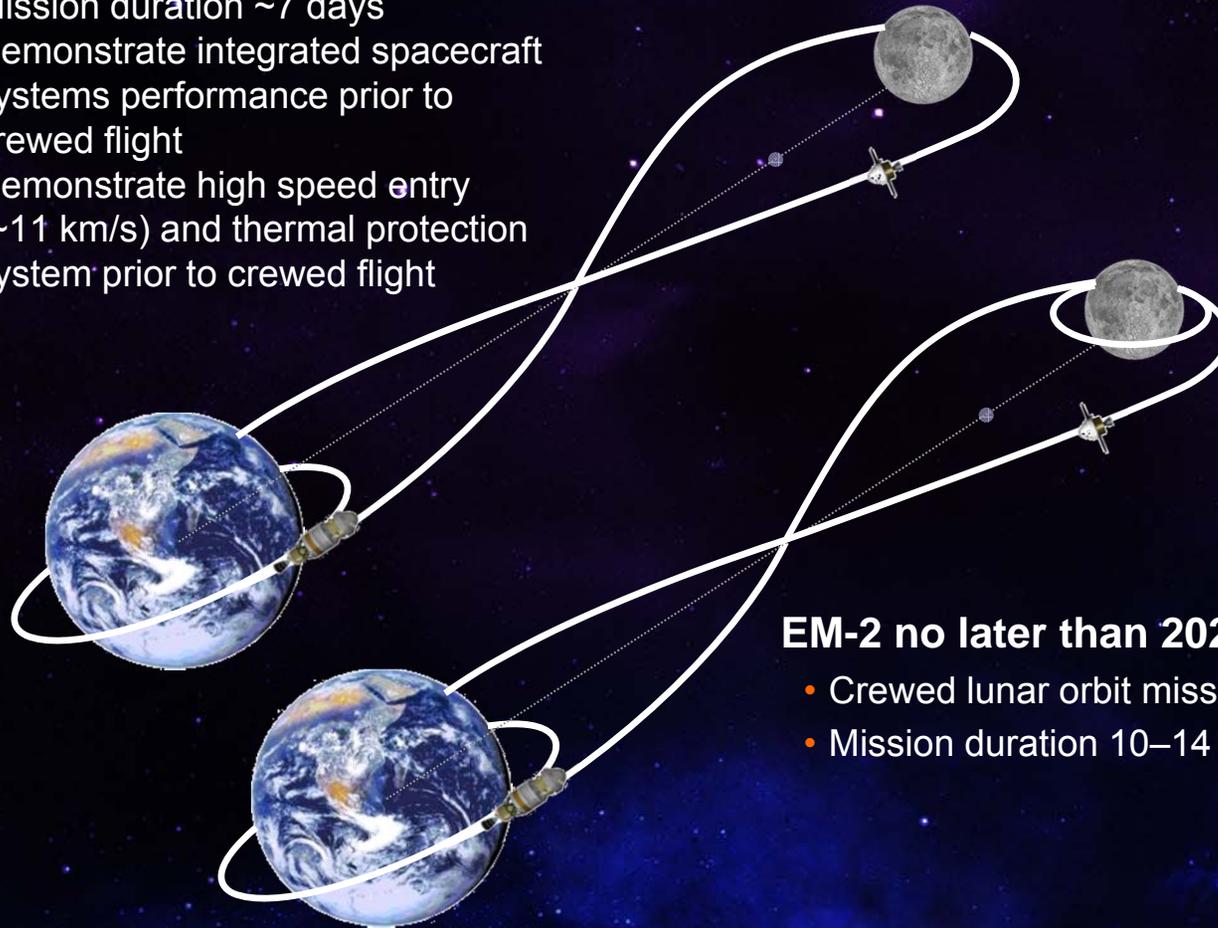
INITIAL CAPABILITY, 2017–21



# 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

## Maximum Dynamic Pressure

Time (sec) 76.4  
 Altitude (ft) 48,189  
 Mach 1.84

## Maximum Boost Stage Axial Acceleration

Time (sec) 110.4  
 Mach No. 3.9

## LAS Jettison

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

## Core Stage Engine Cutoff

Time (sec) 475.2  
 Maximum Acceleration

## SRB Separation

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

## Payload Separation

Time (sec) MECO + 30 sec

Tower Clear & Initiate Roll/Pitch Maneuver  
 9 sec

Gravity Turn minimizes aero loads on vehicle and uses Earth G to turn vehicle horizontal

Roll Maneuver places astronauts in heads-down position

Liftoff + 0.6 sec  
 Time (sec) 0.6

## Launch

At Ignition  
 Time (sec) 0.0  
 Weight (lb) 5,795,338

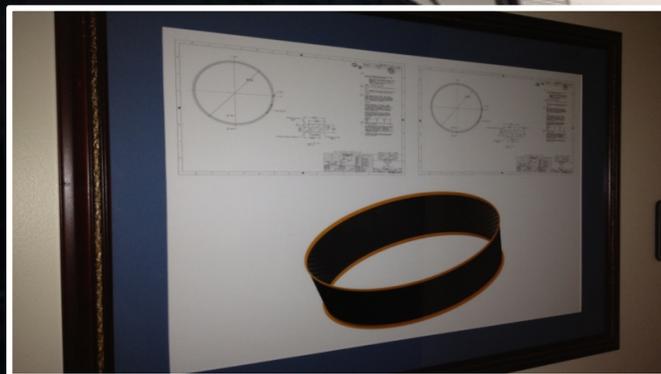
SRB Atlantic Splashdown  
 331 sec  
 (5.5 min)

Core Stage Pacific Splashdown  
 5579 sec  
 (1.5 hrs)

(Not To Scale)

# Exploration Flight Test-1 in 2014

## MPCV Stage Adapter



*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

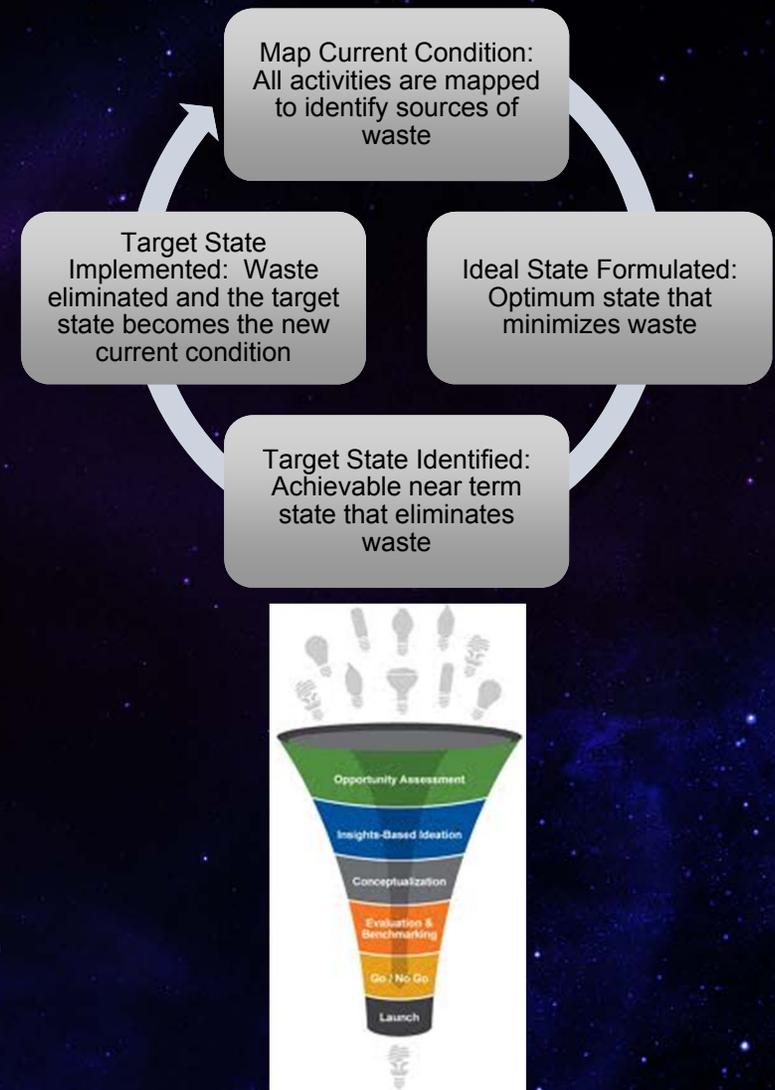
SLS Systems Engineering & Integration Organization	Systems Engineering	Vehicle Management	Structures and Environments	Propulsion	Production	Integrated Avionics & Software	Operations	Test	Safety & Mission Assurance
Program Chief Engineer (CE)	Lead Systems Engineer (LSE)	Discipline Lead Engineer	DLE	DLE	DLE	DLE	DLE	DLE	Chief S&MA Officer
Stages Element Chief Engineer (ECE)	Element LSE (ELSE)	Element DLE (EDLE)	EDLE	EDLE	EDLE	EDLE	EDLE	EDLE	Element CSO (ECSO)
Booster ECE	ELSE	EDLE	EDLE	EDLE	EDLE	EDLE	EDLE	EDLE	ECSO
Engines ECE	ELSE	EDLE	EDLE	EDLE	EDLE	EDLE	EDLE	EDLE	ECSO
Integrated Spacecraft & Payload ECE	ELSE	EDLE	EDLE	EDLE	EDLE	EDLE	EDLE	EDLE	ECSO
Advanced Development ECE									

# 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*

A composite image of space. In the top left is a large, bright yellow sun. In the center is Earth with a small satellite nearby. To the right is Mars with a small moon-like satellite. The bottom half of the image is filled with numerous brown, rocky asteroids of various sizes. The background is a dark blue space filled with stars.

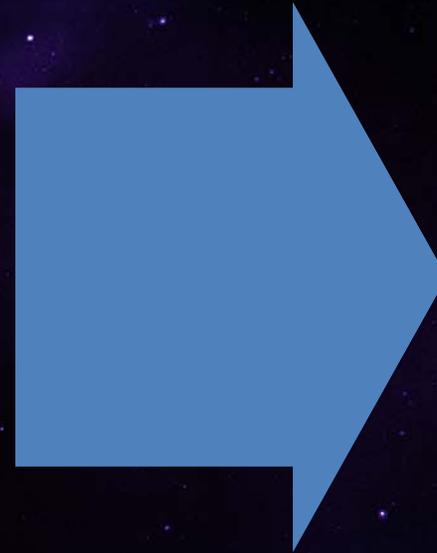
**Alex Priskos, Boosters Manager**  
*SLS Booster Status*

# 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

70 ton Payload  
(Block 1)



130 ton Payload  
(Block 2)



## ◆ 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



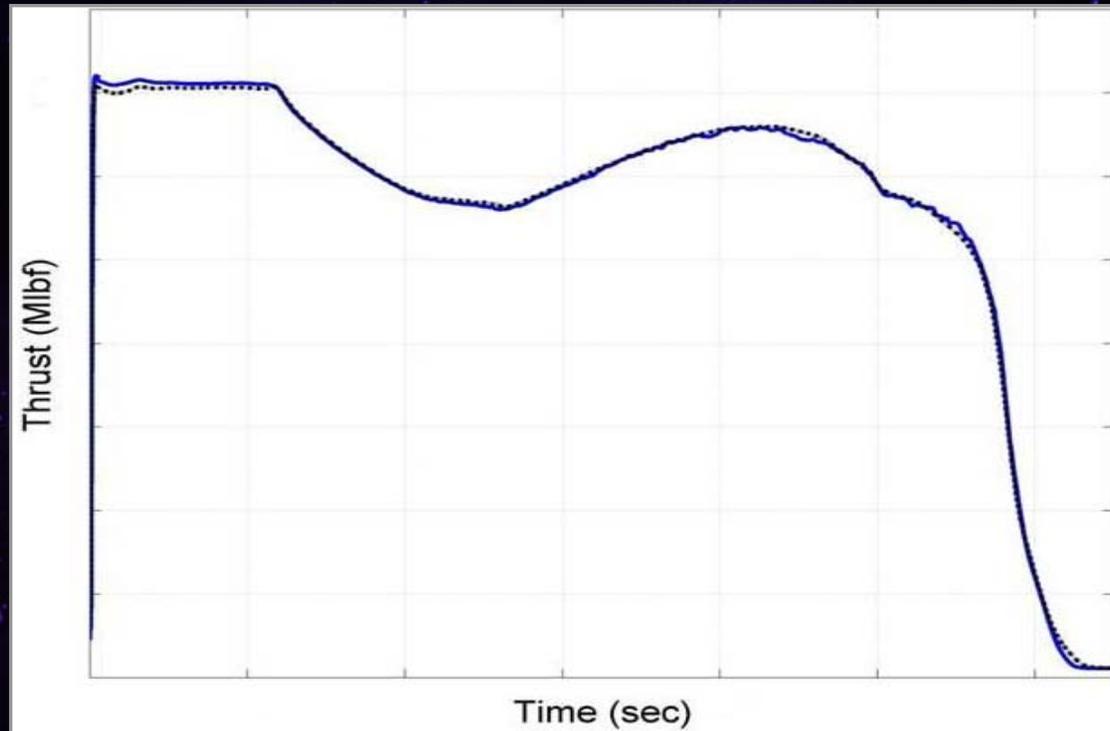
**DM-3 Static Test**



**DM-1 Nozzle post-fire inspection**

# Development Motor Test Status – Motor Performance

DM-3 Vacuum Thrust at Reference Conditions

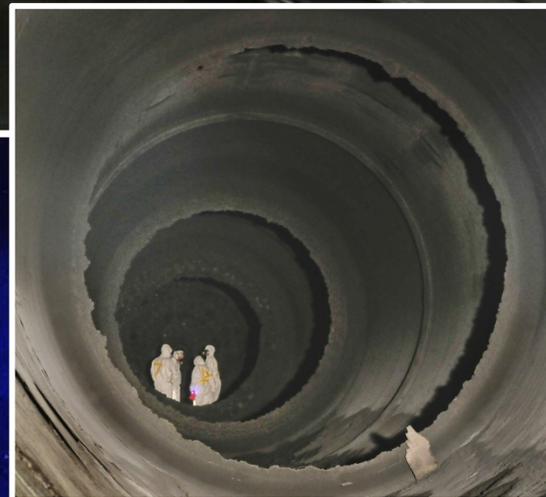


DM-1 Static Test

# Development Motor Test Status – Insulation

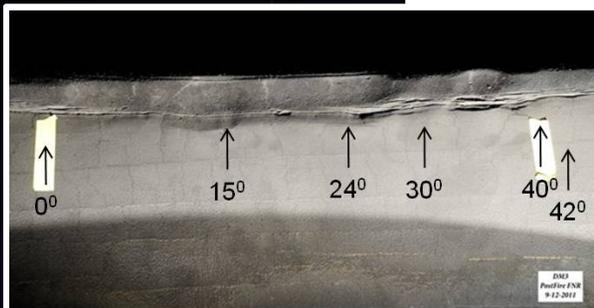


Layup process of PBI -  
NBR insulator

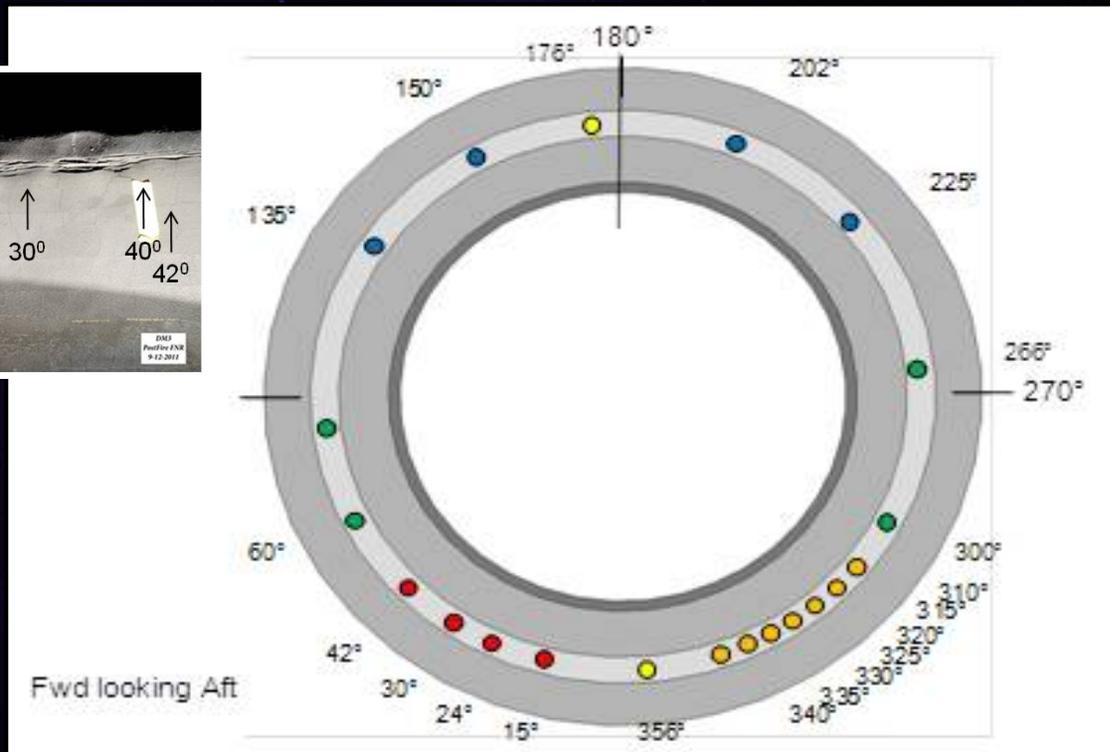


Post-test inspection of  
DM-1 insulator

# Development Motor Test Status – Nozzle



DM-3 FNR post-test

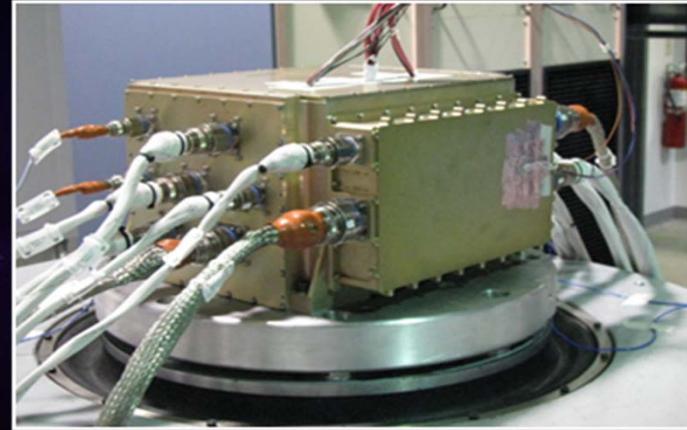


DM-3 UT locations

# Booster Avionics Testing



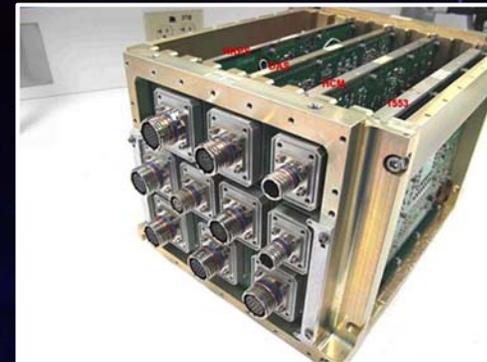
**Avionics Flight Control Test-1**



**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

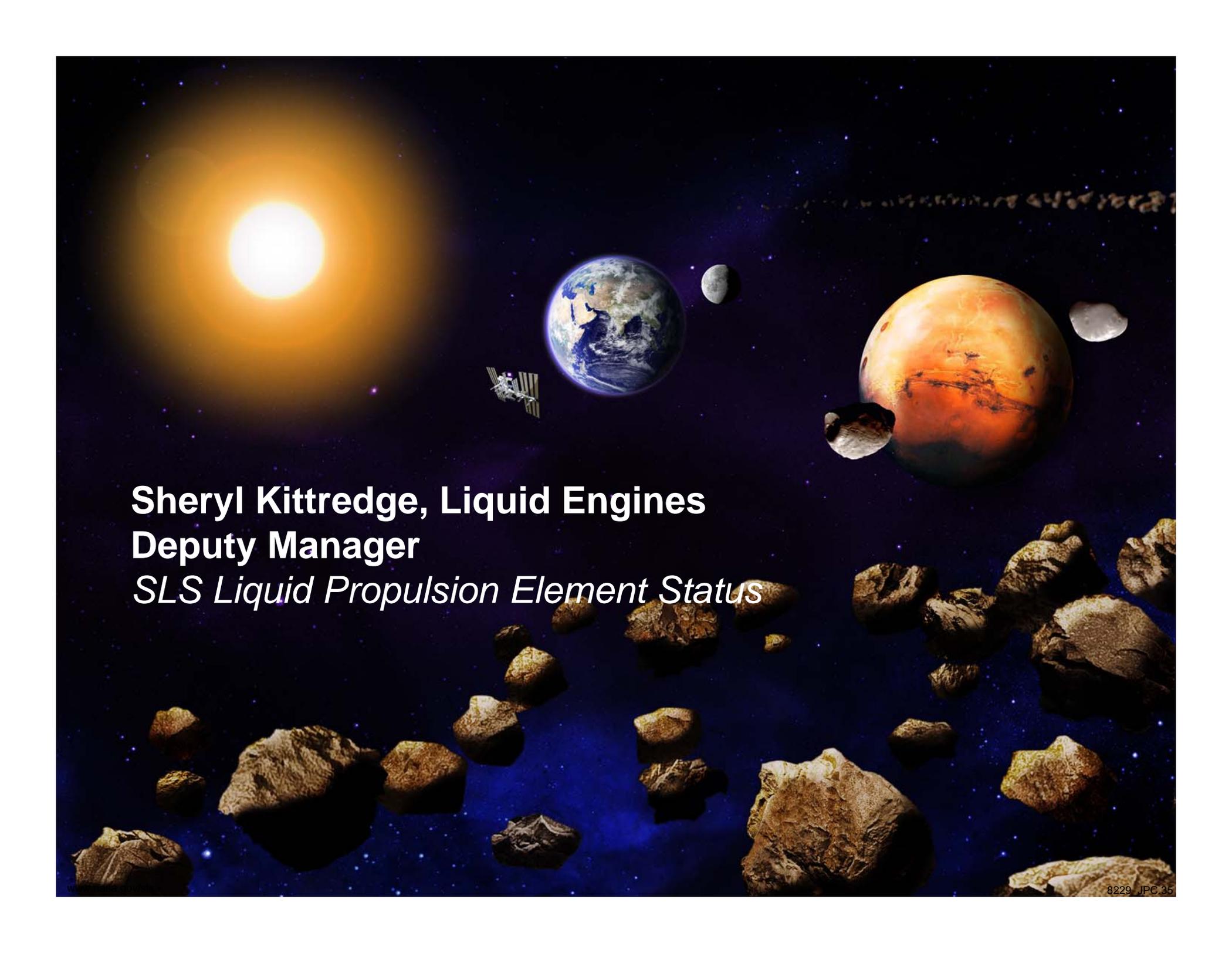
# NASA's Space Launch System Boosters Element Summary

- ◆ **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](http://www.nasa.gov/sls)

A composite image of space. In the top left, a bright yellow sun glows. In the center, Earth is shown with a small satellite orbiting it. To the right, Mars is depicted with a cratered surface and a small moon. The bottom half of the image is filled with numerous brown, rocky asteroids of various sizes.

**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

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

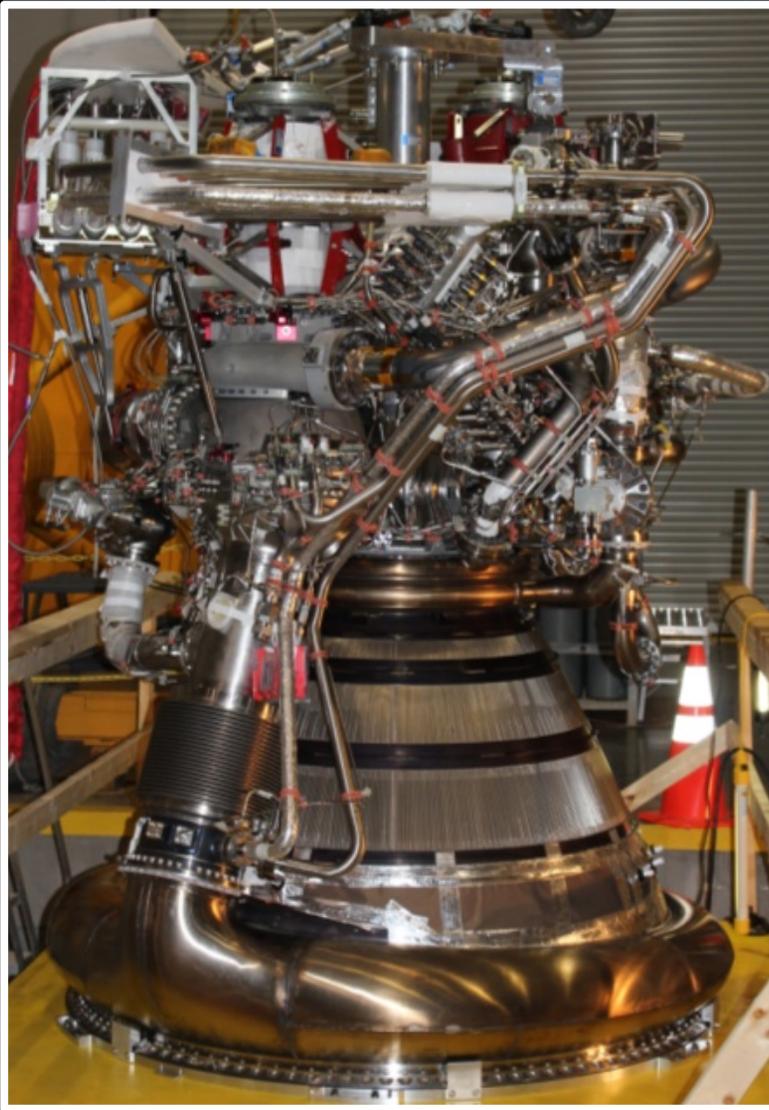


**15 RS-25 engines -previously stored at KSC Engine shop -now housed at Building 9101 at SSC**

# RS-25 Engine Inventory (At End of FY12)

Flight Engines			Dev Engines
Assembled and Ready for Test	Acceptance Testing Required	Some Fab and Assembly Required	Some Fab and Assembly Required
    2044 2045 2047 2048    2050 2051 2052     2054 2056 2057 2058    2059 2060 2061	 2062	 2063	 0525  0528

# Upper Stage Engine J-2X

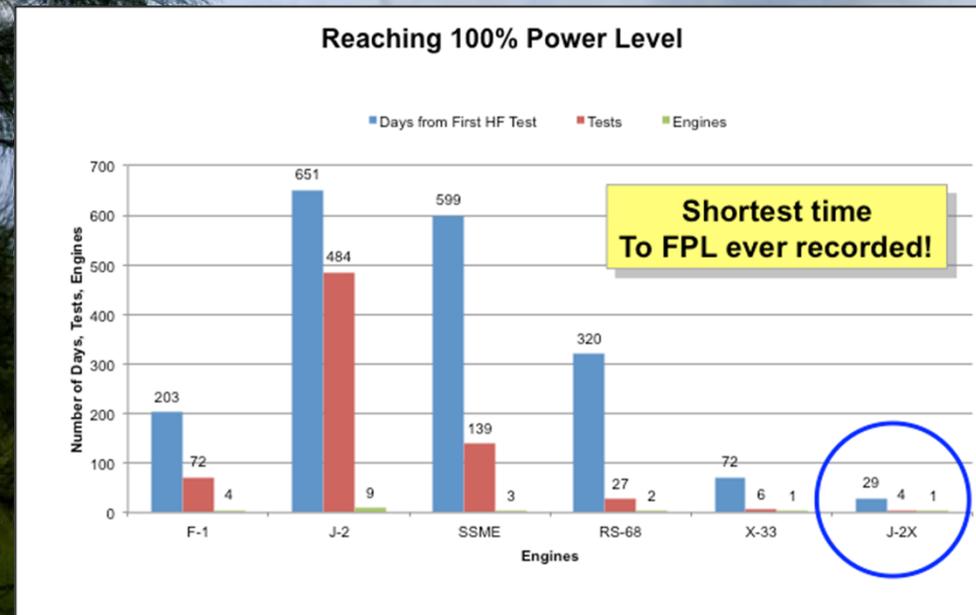


◆ Cycle	Gas Generator
◆ Thrust, vac (klbs)	294 (285K*)
◆ Isp, vac (sec)	448 (436*)min
◆ Pc (psia)	1,337
◆ MR	5.5
◆ AR	92 (59*)
◆ Weight (lbm)	5,450 max
◆ Secondary Mode MR	4.5
◆ Secondary Mode PC	~82%
◆ Restart	Yes
◆ Operational Starts	8
◆ Operational Seconds	2,600
◆ Length (in), Max	185
◆ Exit Dia.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



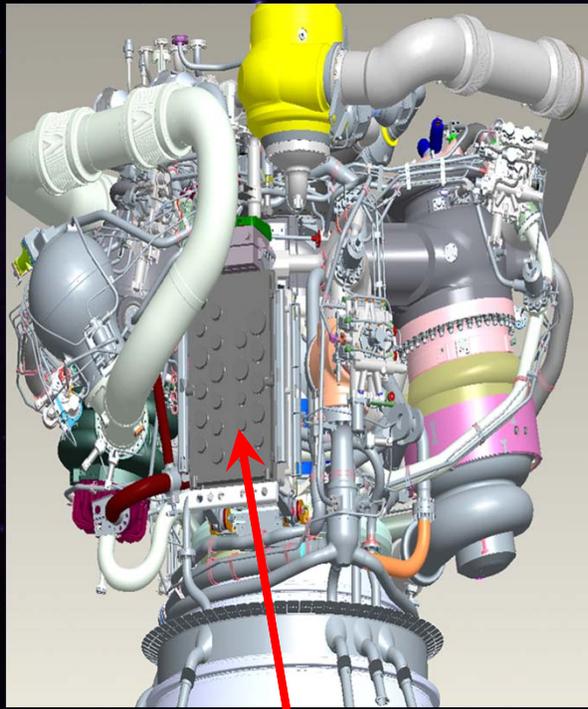
Test 1 July 7th - Chill  
Test 2 July 14th - 1.9s, Ignition  
Test 3 July 26th - 3.7s, 103% PL  
Test 4 Aug 5th - 7.0s, 100% PL  
Test 5 Aug 17th - 32.3s, 103% PL  
Test 6 Sep 28th - 40.0s, 103% PL  
Test 7 Oct 25<sup>th</sup> - 140.0s, 100% PL  
Test 8 Nov 9<sup>th</sup> - 500.0s, 100%PL

# J-2X Engine Inventory

## Manufacturing and Assembly Status

Assembly Complete and In Testing	Ready to Assemble	In Manufacturing
 <p>E10001</p>	 <p>E10002</p>  <p>E10003</p>	 <p>E10004</p>  <p>E10005</p>

# RS-25 Engine Controller Overview



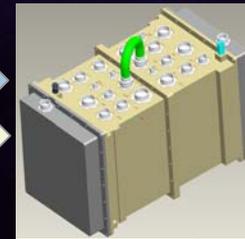
RS-25 Engine Controller

SSMEC

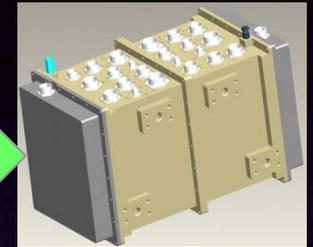


J-2X ECU

RS-25 CSEC  
(Core Stage Engine  
Controller)



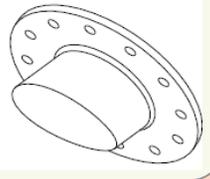
Universal  
Engine Controller



# 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

✓ Procurement of SLM machine for MSFC Materials Lab.

✓ Mechanical testing of material samples, developing materials verification matrix

✓ 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



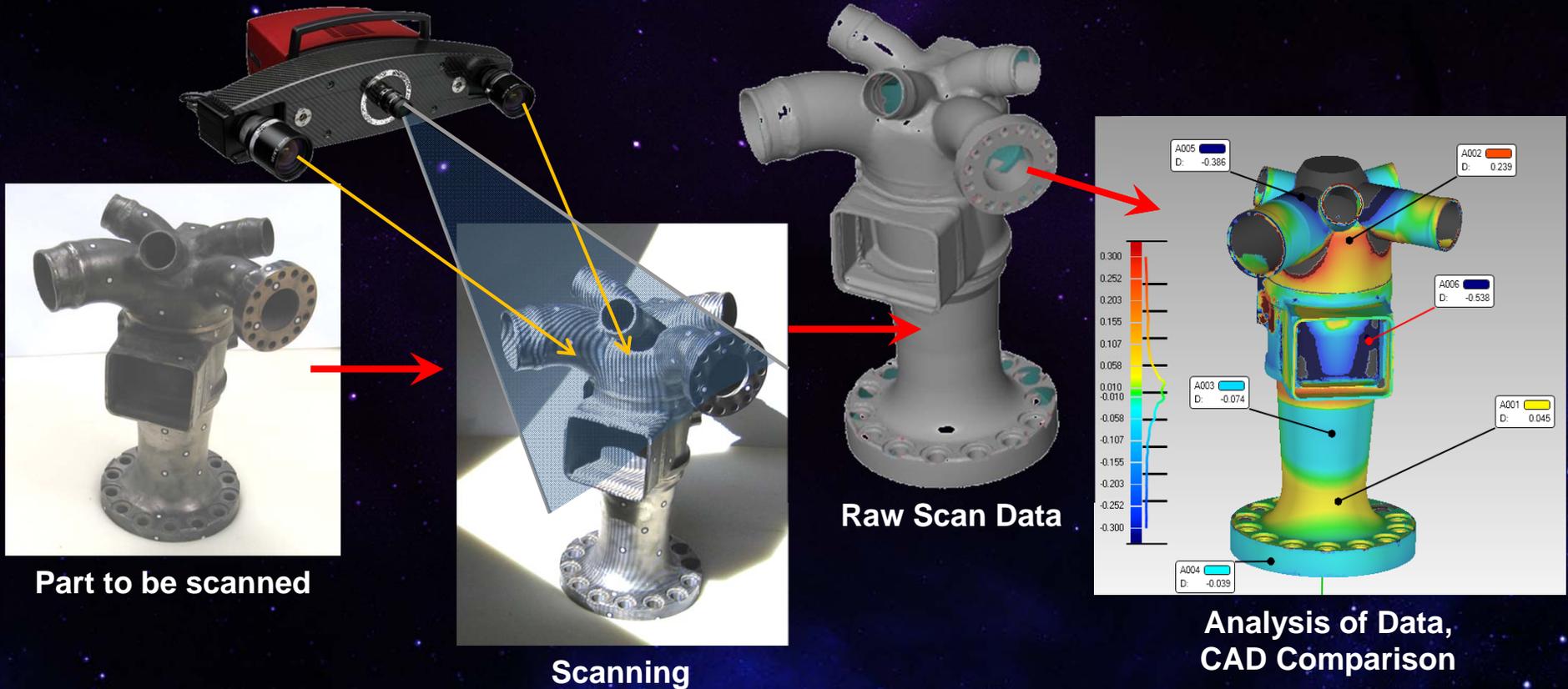
Build flight rationale

Fly SLM components in 2017.

✓ Activity Completed  
✓ Activity in work

# Structured Light

RS25 Mixer

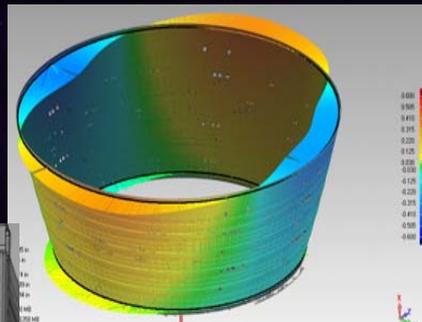


# SLS Structured Light Examples

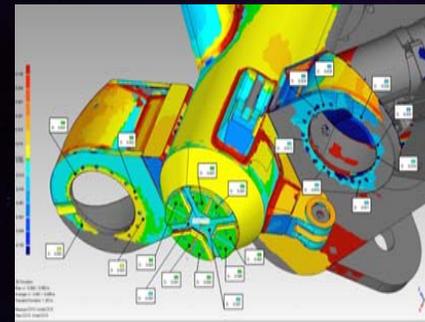
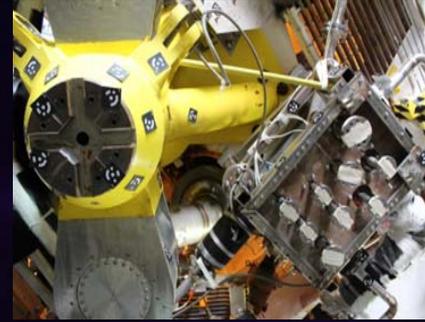
Engine Interface Adjustment



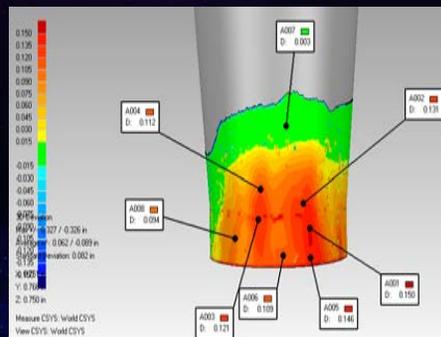
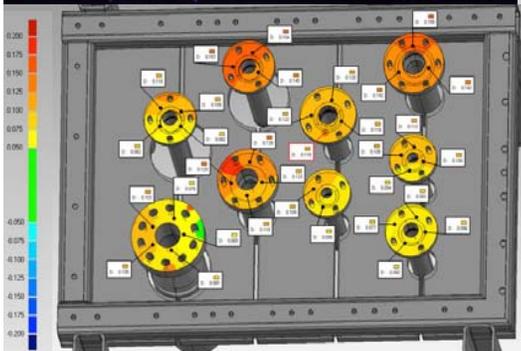
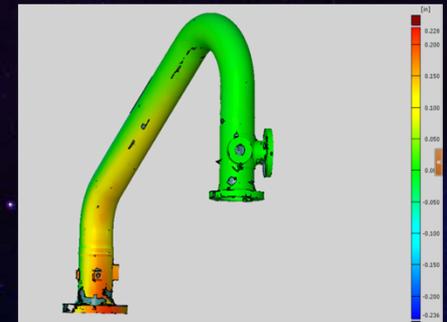
J-2X Extension



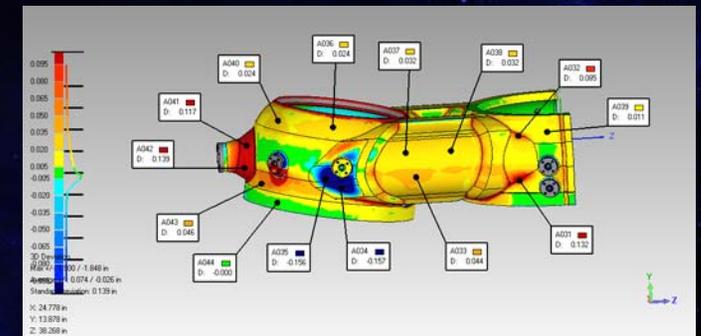
J-2X Engine Integration



J-2X Duct Alignment



ASI Erosion Mapping



RS25 Powerhead Reverse Engineering

# 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](http://www.nasa.gov/sls)*

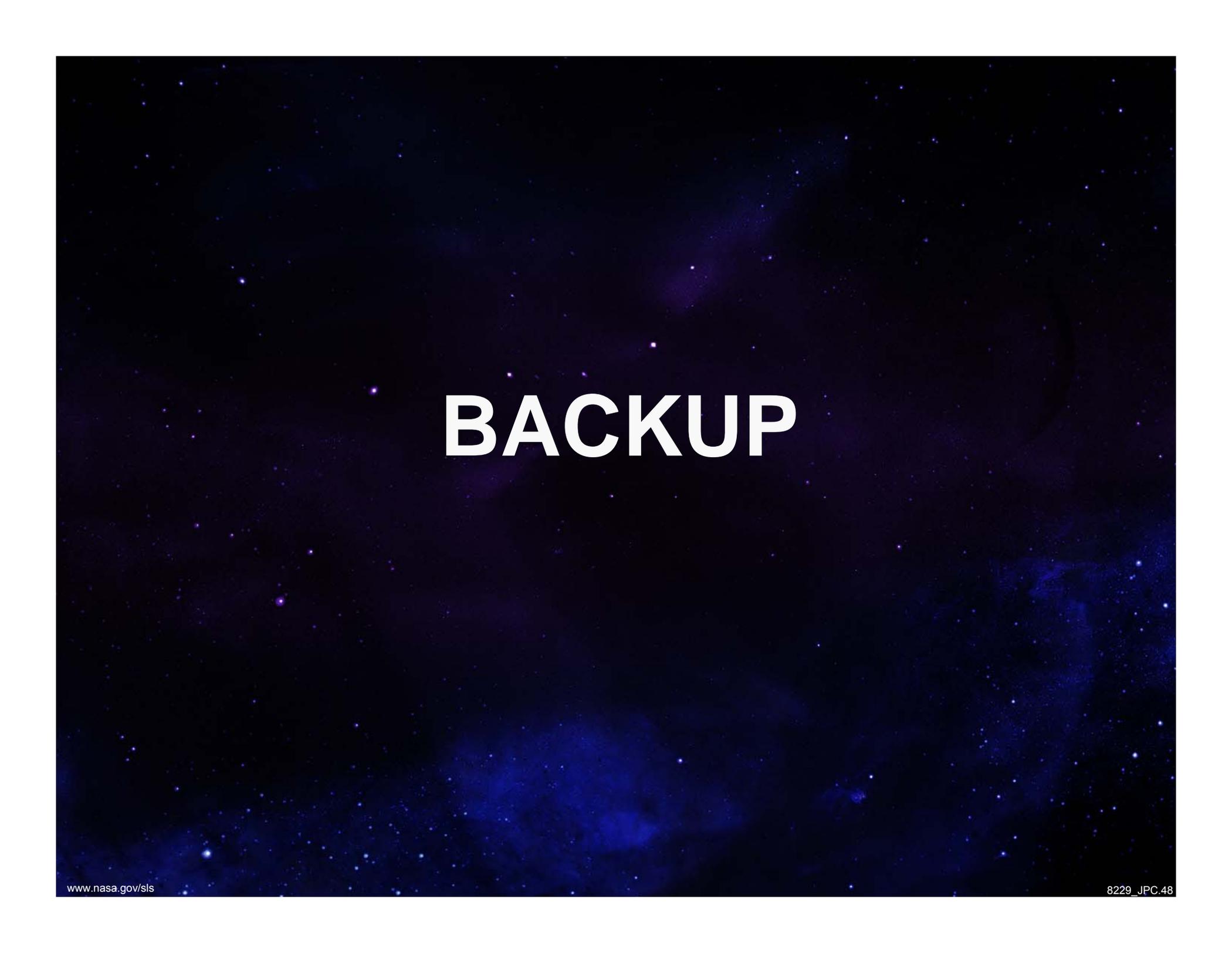


*Somewhere, something incredible  
is waiting to be known.*  
— Carl Sagan



**For More Information**

***[www.nasa.gov/sls](http://www.nasa.gov/sls)***



**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

