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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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 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.

National Aeronautics and Space Administration

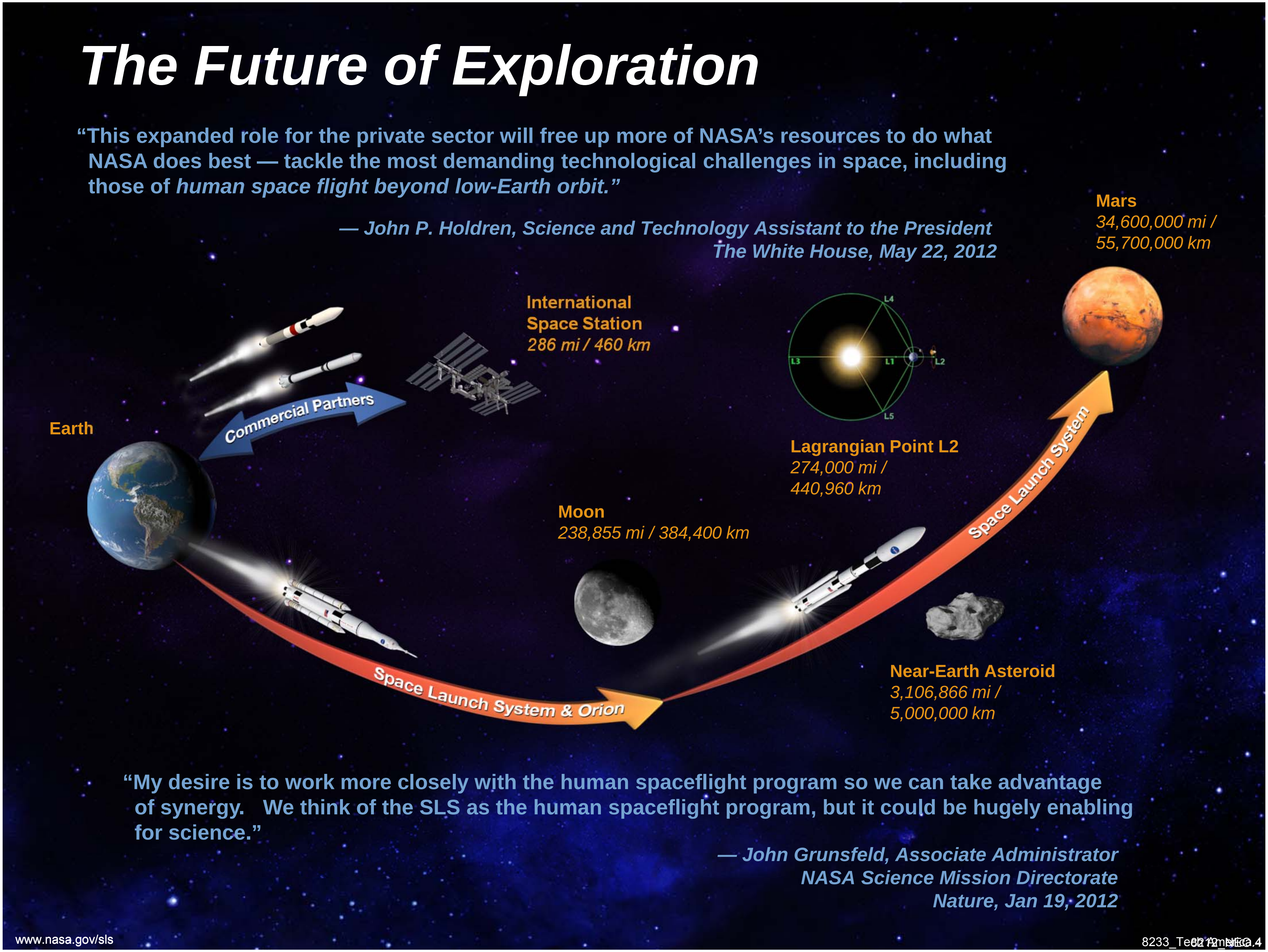
Propulsion Progress for NASA's Space Launch System

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
www.nasa.gov/sls
8229_JPC.2

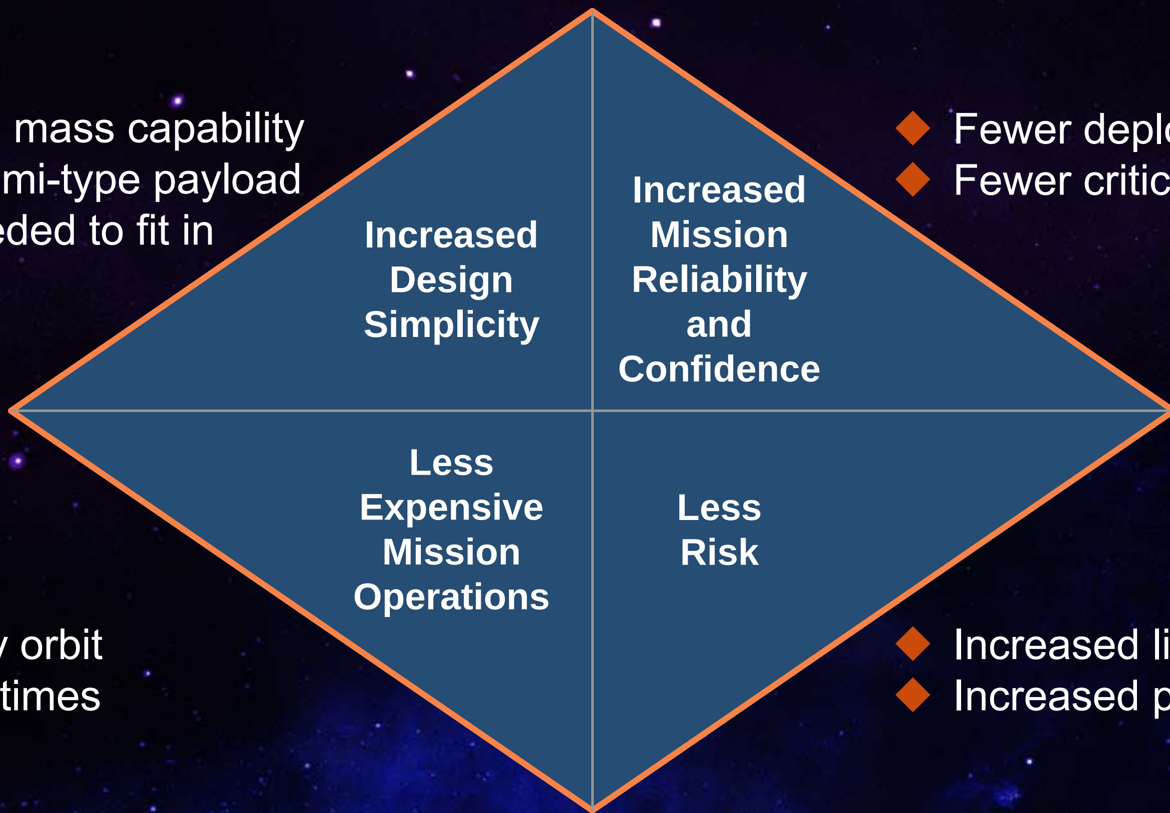

"To reach for new heights...
and reveal the unknown so that what we do and learn will benefit all humankind."
National Aeronautics and Space Administration
NASA
L4
L3
L1
L2
L5
• Extend and sustain human activities across the solar system.
• Expand scientific understanding of the Earth and the universe in which we live.
NASA 2011 Strategic Plan
SLS Launches in 2017
www.nasa.gov/sls
8229_JPC.3


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
Mars
34,600,000 mi /
55,700,000 km
International
Space Station
286 mi / 460 km
L4
L3
L1
L2
L5
Earth
Commercial Partners
Lagrangian Point L2
274,000 mi /
440,960 km
Moon
238,855 mi / 384,400 km
Space Launch System
Space Launch System & Orion
Near-Earth Asteroid
3,106,866 mi /
5,000,000 km
"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
www.nasa.gov/sls

SLS Benefits for Exploration

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

- Fewer deployments
- Fewer critical operations



- High-energy orbit
- Shorter trip times

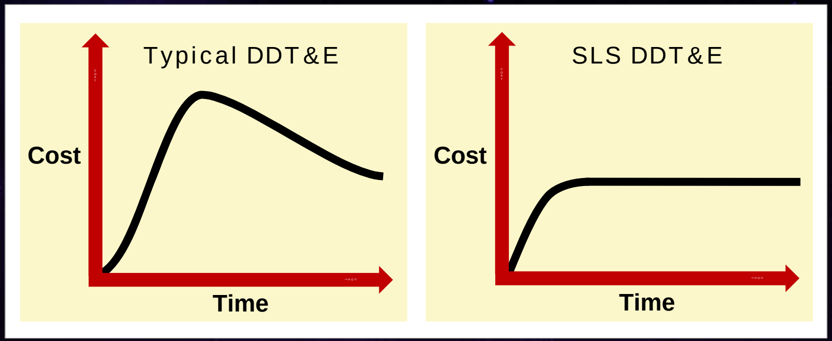
- Increased lift capacity
- Increased payload margin

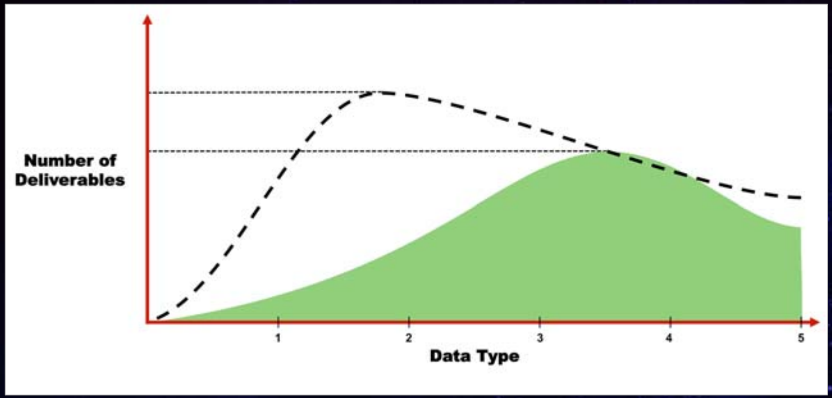
Safe, Affordable, Sustainable


Building a National Infrastructure Asset
For Beyond-Earth Orbit Exploration
www.nasa.gov/sls
8229_JPC.6

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:

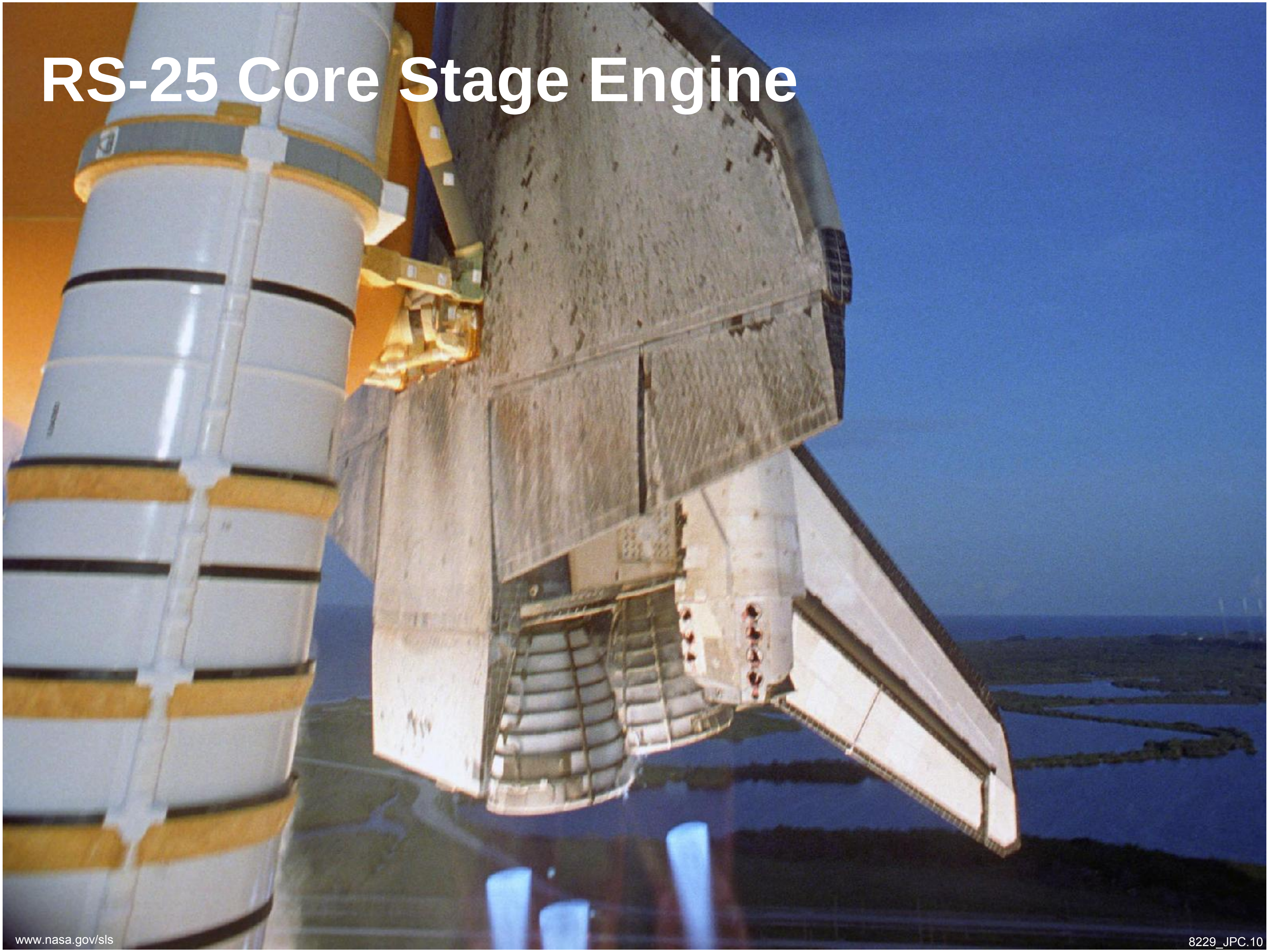
- Same diameter (27.5 ft.) and basic design
- Manufacturing facilities, tooling, materials, and processes/practices
- Workforce
- Supply chain/industry base
- Transportation logistics
- Ground systems/launch infrastructure
- Propellants

130 ton Payload
(Block 2)

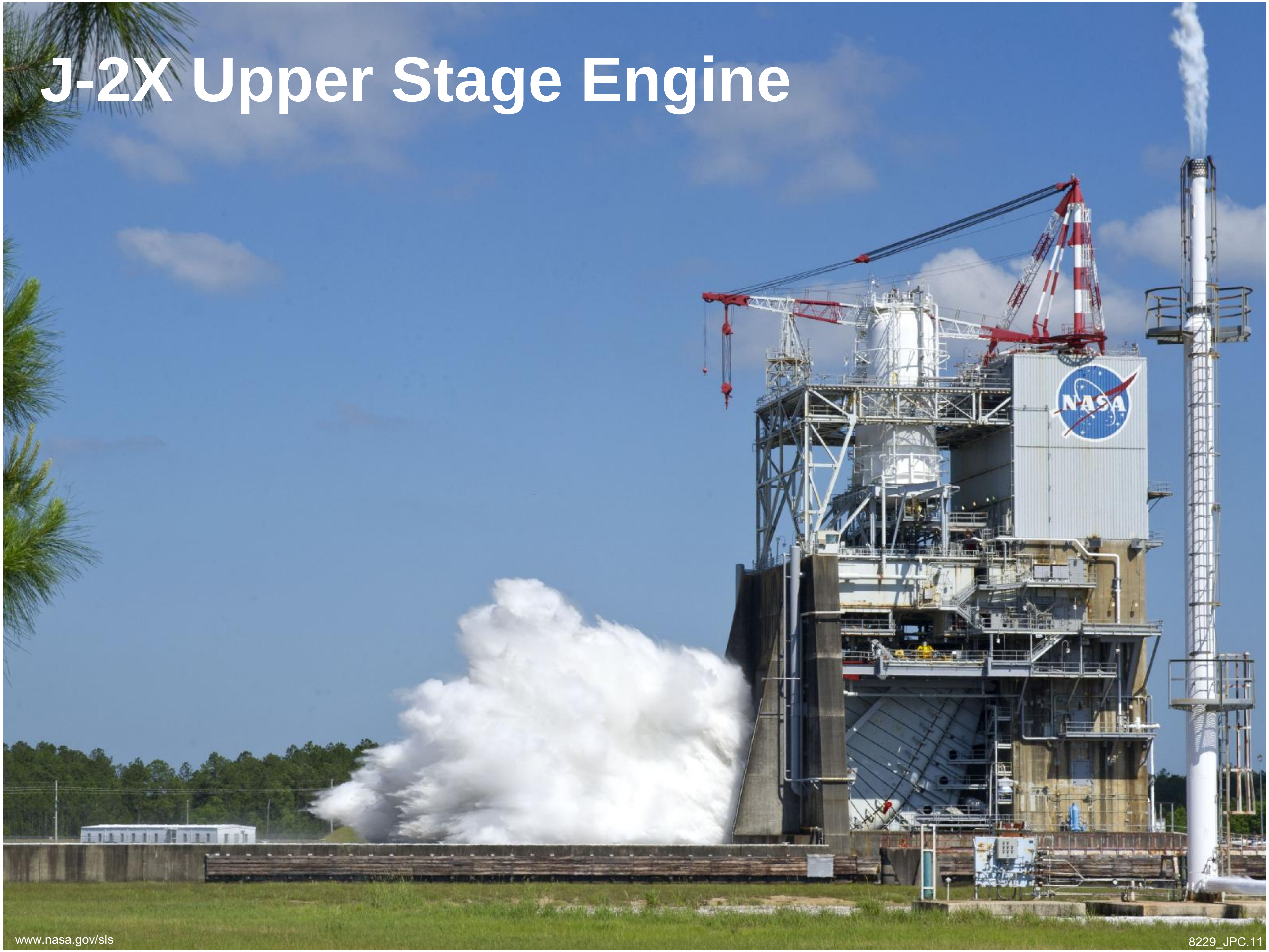
RS-25 Core Stage Engines


5-Segment Solid Rocket Booster
Development Motor Test 3
Sep 8, 2011
ATK Promontory, UT
www.nasa.gov/sls
8229_JPC.9

RS-25 Core Stage Engine



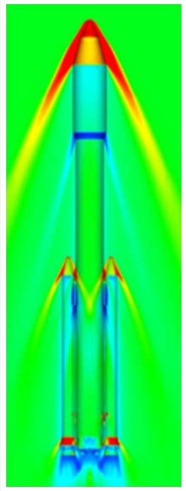
J-2X Upper Stage Engine



Partnering with Marshall and Michoud

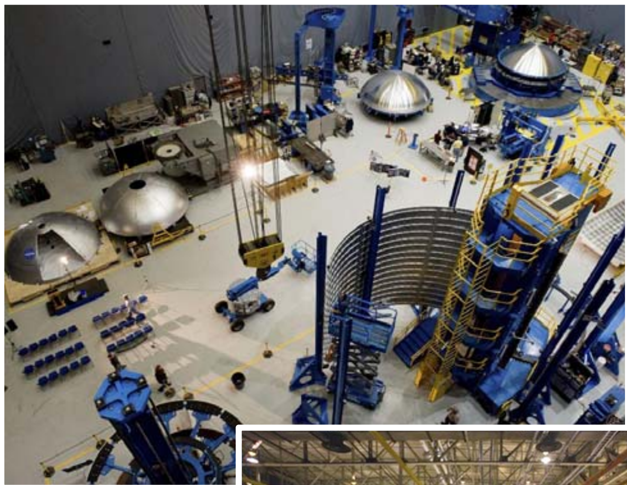
- **Avionics Test-Bed**
  May 2012

- **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

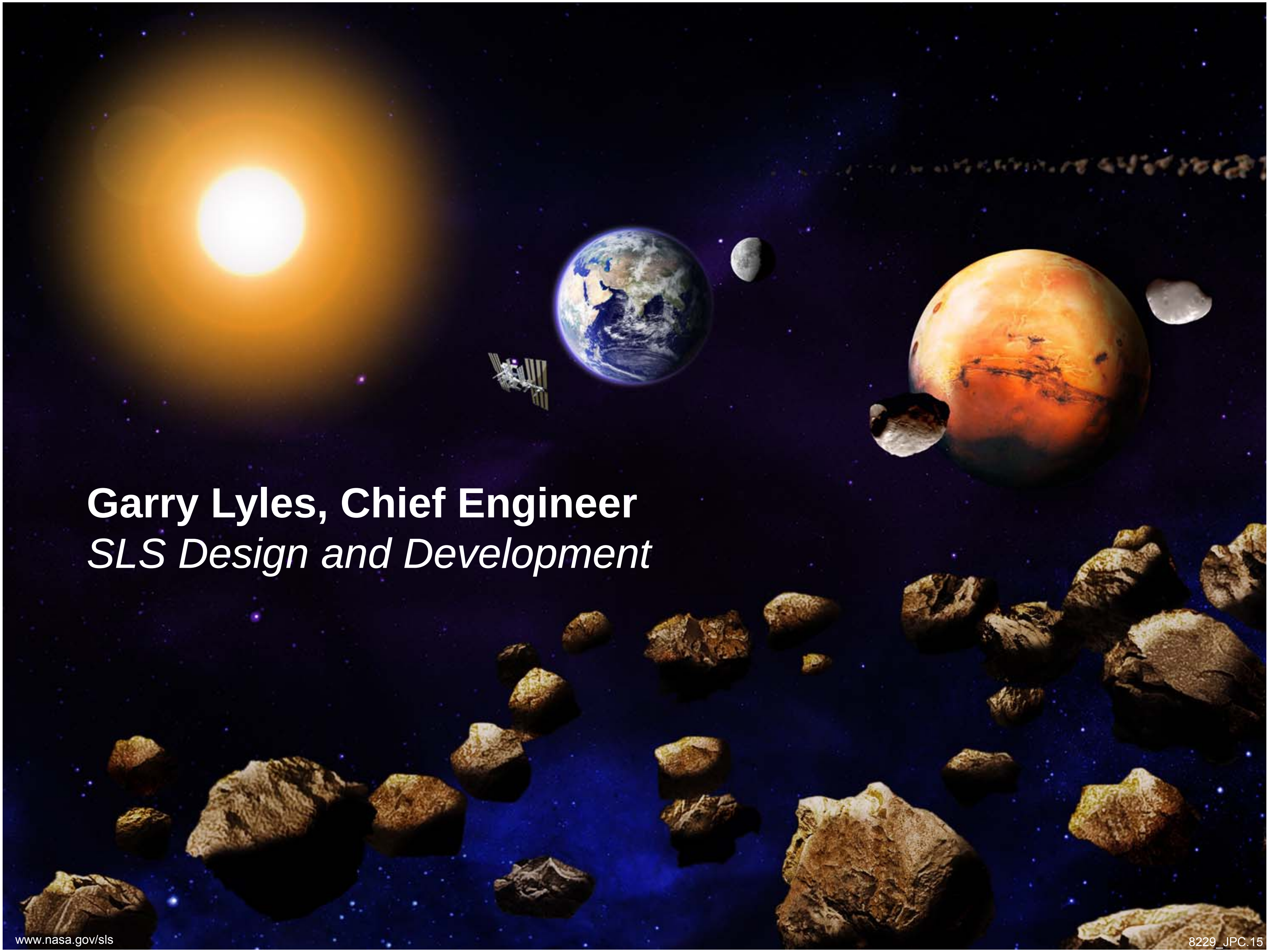
Preliminary Design Review 2013

Launching in 2017

For More Info: www.nasa.gov/sls

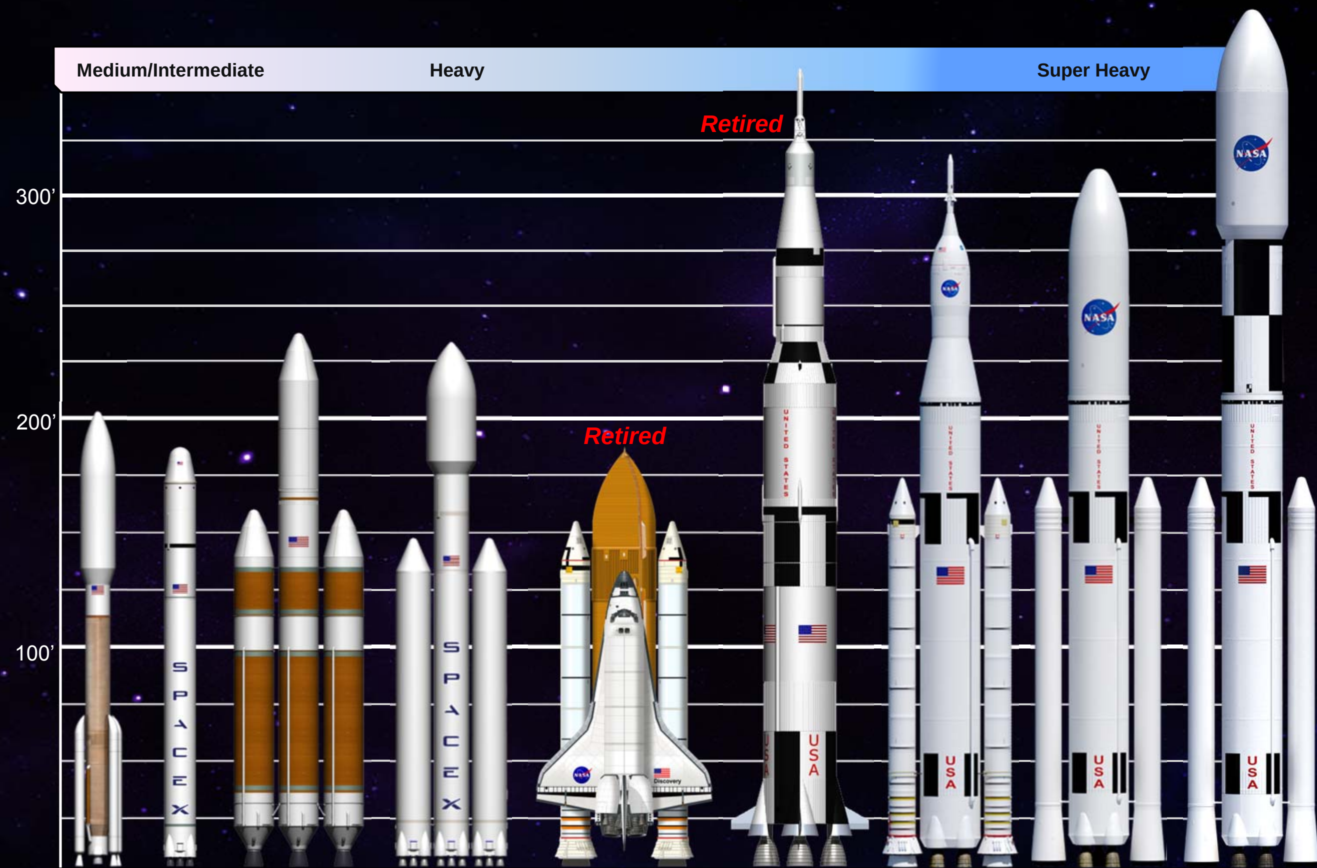
Garry Lyles, Chief Engineer

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
Moon: 238,855 mi / 384,400 km
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
Surface Capabilities Needed
Advanced Propulsion Needed
High Thrust In-Space Propulsion Needed
Long Duration Habitat Needed
ISS: 286 mi / 460 km
SLS —
Going Beyond Earth's Orbit
www.nasa.gov/sls
8229_JPC.16

SLS Will Be the Most Capable Launch Vehicle



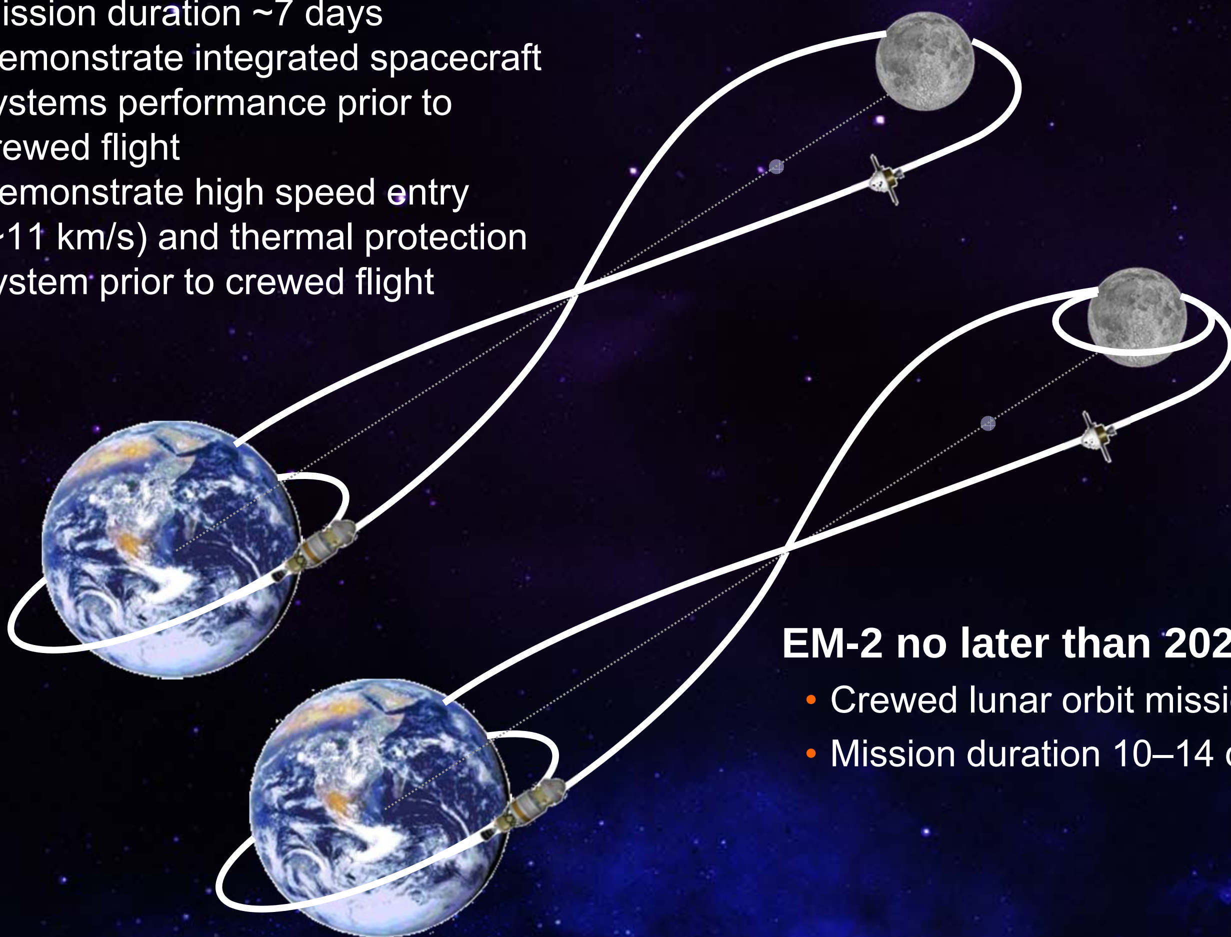
	ULA Atlas V 551	SpaceX Falcon 9	ULA Delta IV H	SpaceX Falcon 9 Heavy	NASA Space Shuttle	NASA Saturn V	NASA SLS 70 t	NASA SLS 105 t	NASA SLS 130 t
Volume (ft³)	7,840	5,156	7,133	5,156	10,559	18,434	19,105	19,105	19,105
(m³)	222	146	202	146	299	522	541	541	541
Payload (lbs)	40,780	23,050	49,736	117,000	55,000	262,000	154,323	231,485	286,601
(kg)	18,500	10,455	22,560	53,070	24,947	118,841	70,000	105,000	130,000

SLS Initial Capability

Initial Exploration Missions (EM)

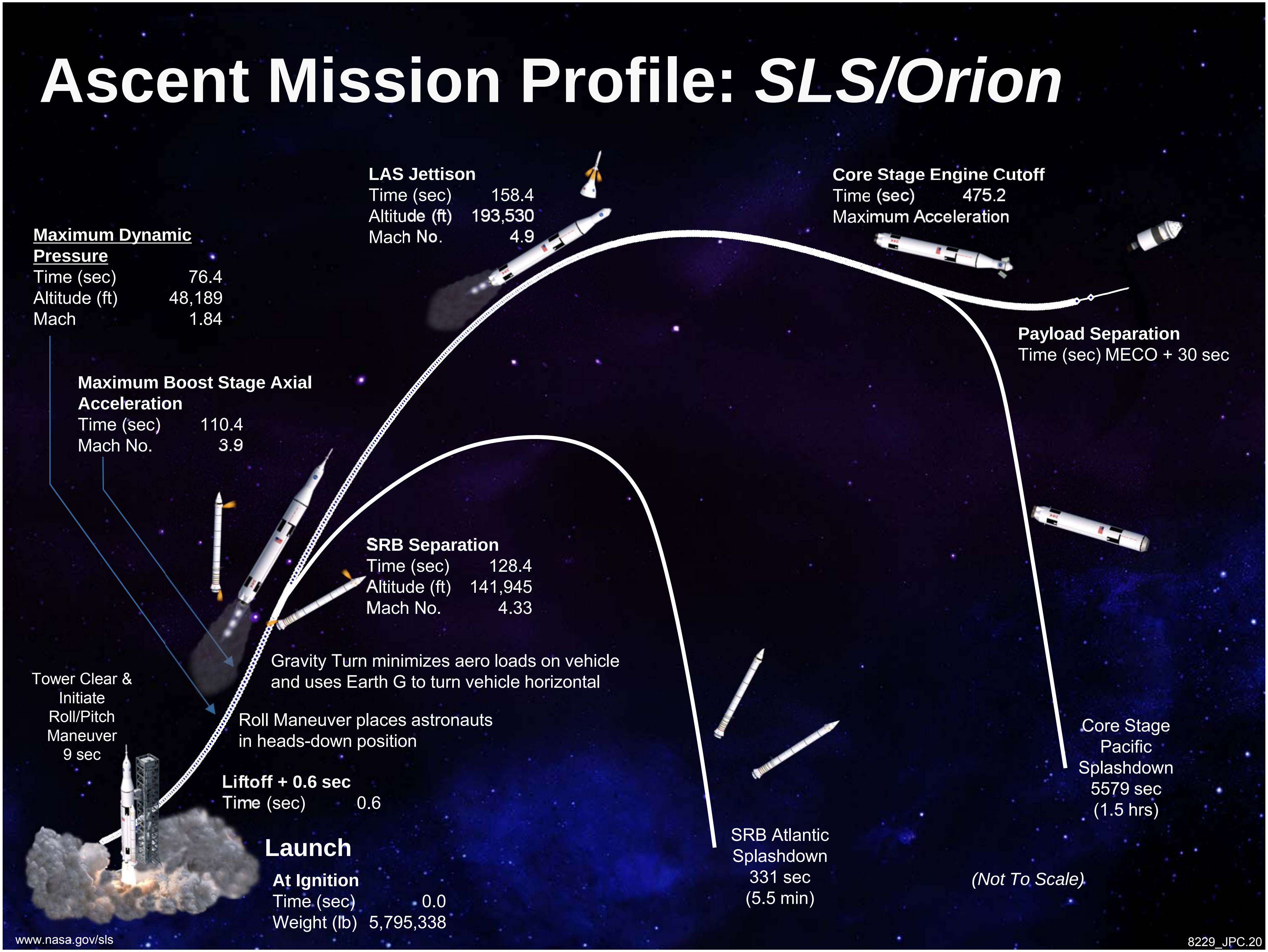
EM-1 in 2017

- 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
LAS Jettison
Time (sec) 158.4
Altitude (ft) 193,530
Mach No. 4.9
Core Stage Engine Cutoff
Time (sec) 475.2
Maximum Acceleration
Payload Separation
Time (sec) MECO + 30 sec
Maximum Boost Stage Axial Acceleration
Time (sec) 110.4
Mach No. 3.9
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
Tower Clear & Initiate Roll/Pitch Maneuver 9 sec
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)
www.nasa.gov/sls
8229_JPC.20

Exploration Flight Test-1 in 2014
MPCV Stage Adapter

EFT-1 MPCV Stage Adapter Design Review in March 2012

SLS Technical Communication Integration

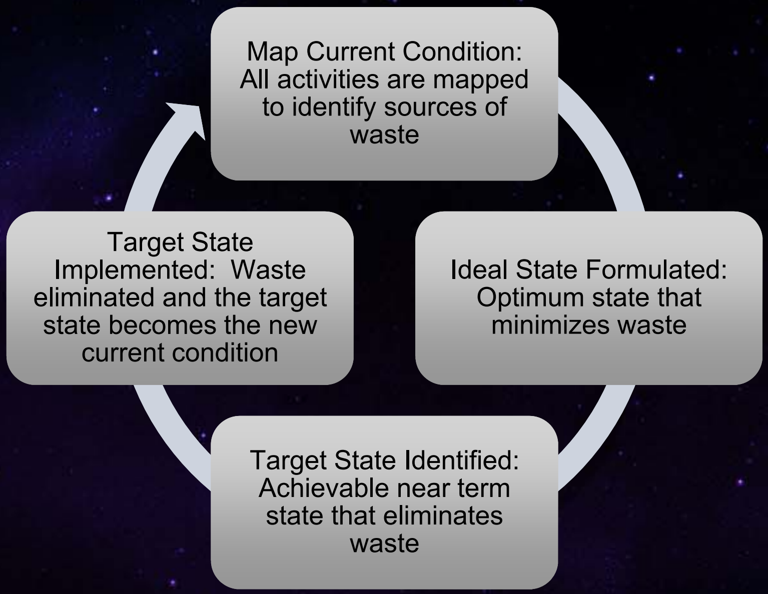
- **Accountability and Responsibility**
  - Strong focus on technical leadership
  - Chief Engineer serves as lead designer
  - Chief Engineer and staff focused on technical integration
  - Organized to balance functional expertise and cross-functional integration
  - Early integration of production 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**

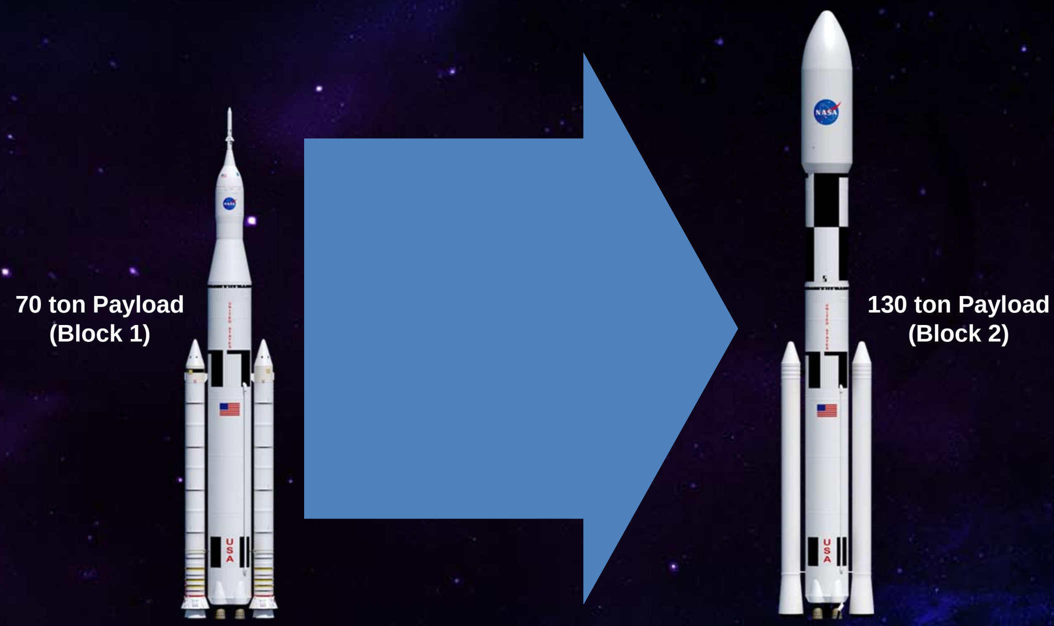
On Track for First Flight in 2017

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)**

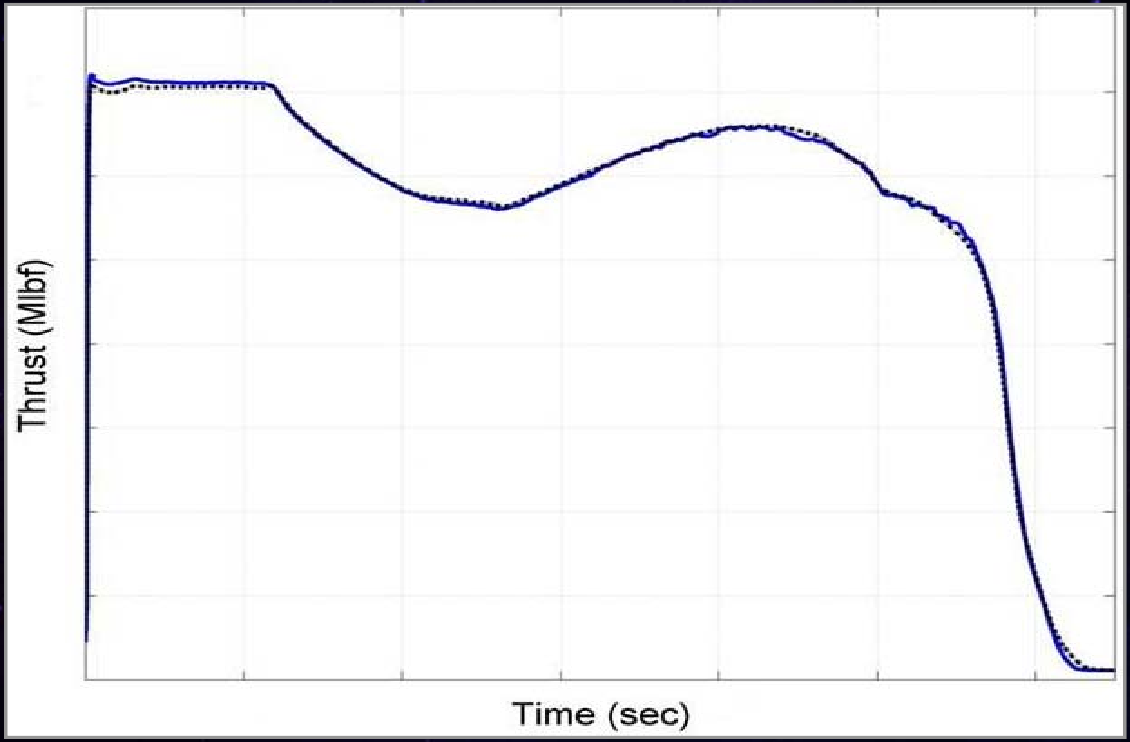
Development Motor Test Status – Static Tests

DM-3 Static Test

DM-1 Nozzle post-fire inspection

Development Motor Test Status – Motor Performance

DM-3 Vacuum Thrust at Reference Conditions



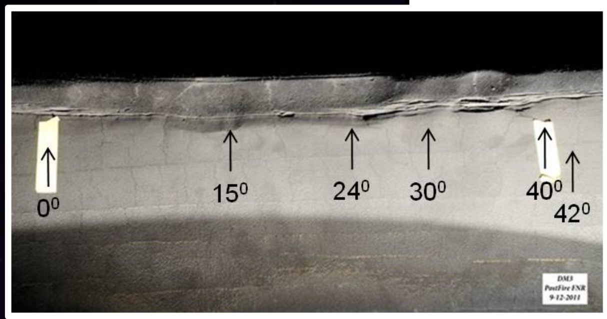
DM-1 Static Test

Development Motor Test Status – Insulation

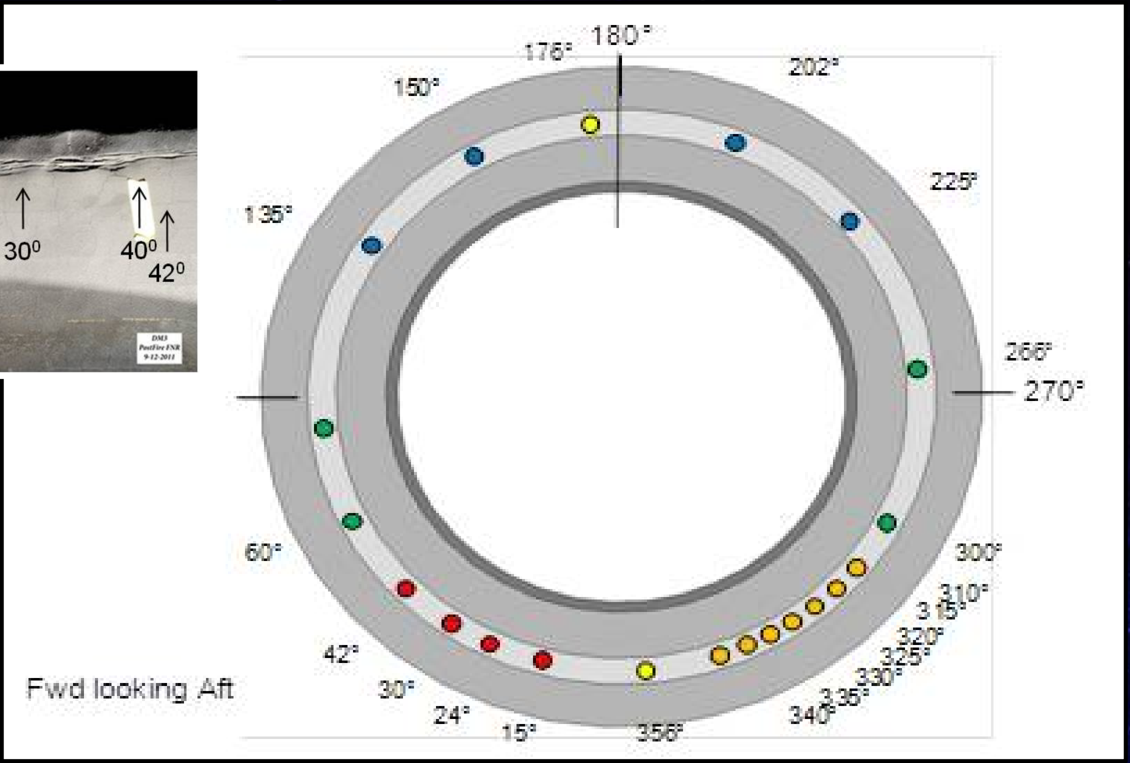
Layup process of PBI - NBR insulator

Post-test inspection of DM-1 insulator

Development Motor Test Status – Nozzle



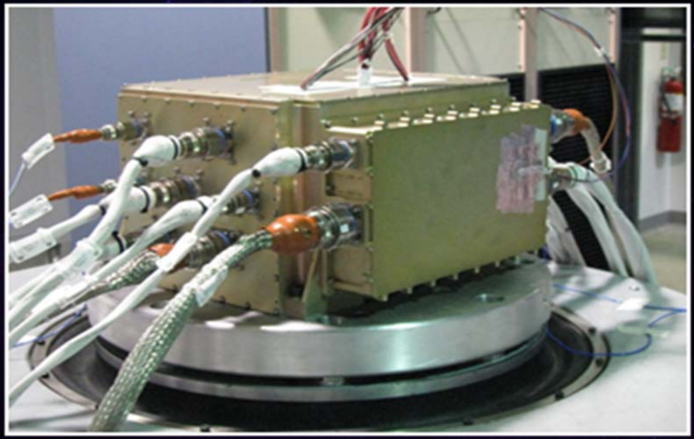
DM-3 FNR post-test



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
www.nasa.gov
8229_JPC.35

Core Stage Engine (RS-25)

Core Stage Engine	*Existing RS-25 Inventory*	*New Build RS-25*
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)	***512,185***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

Assembled and Ready for Test


2044

2045

2047

2048

2050

2051

2052

2054

2056

2057

2058

2059

2060

2061

Acceptance Testing Required


2062

Some Fab and Assembly Required


2063

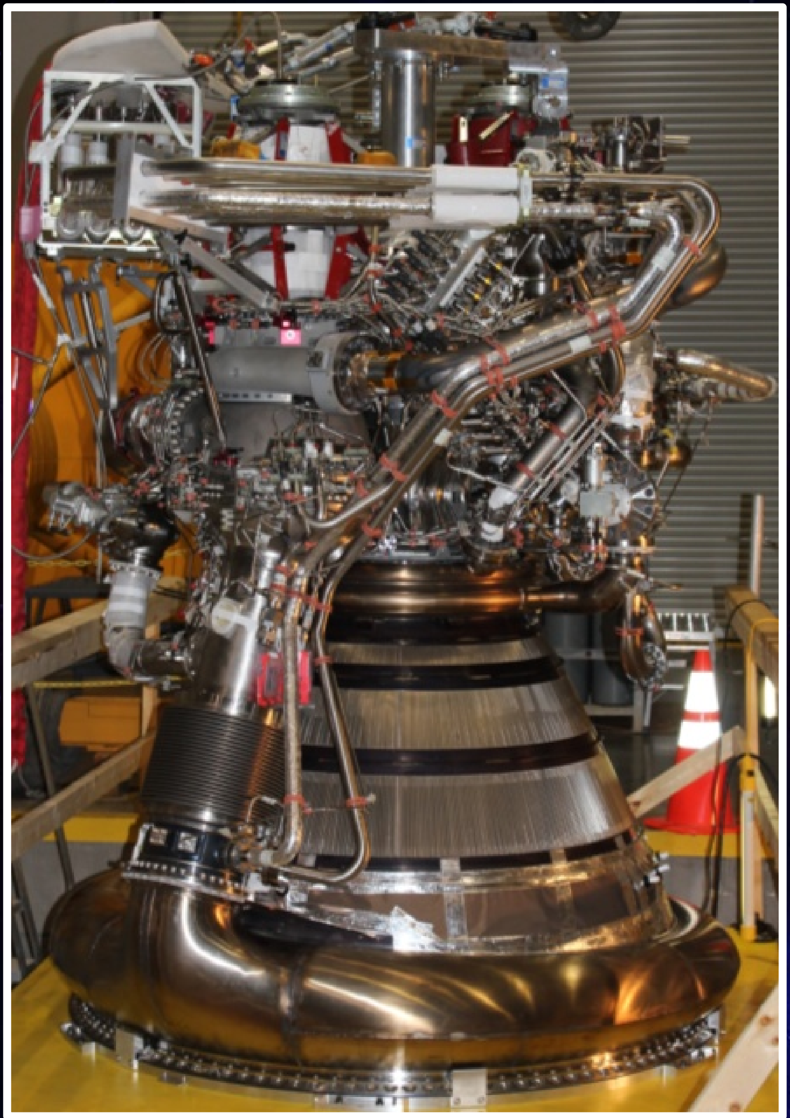
Dev Engines

Some Fab and Assembly Required


0525

0528

Upper Stage Engine J-2X

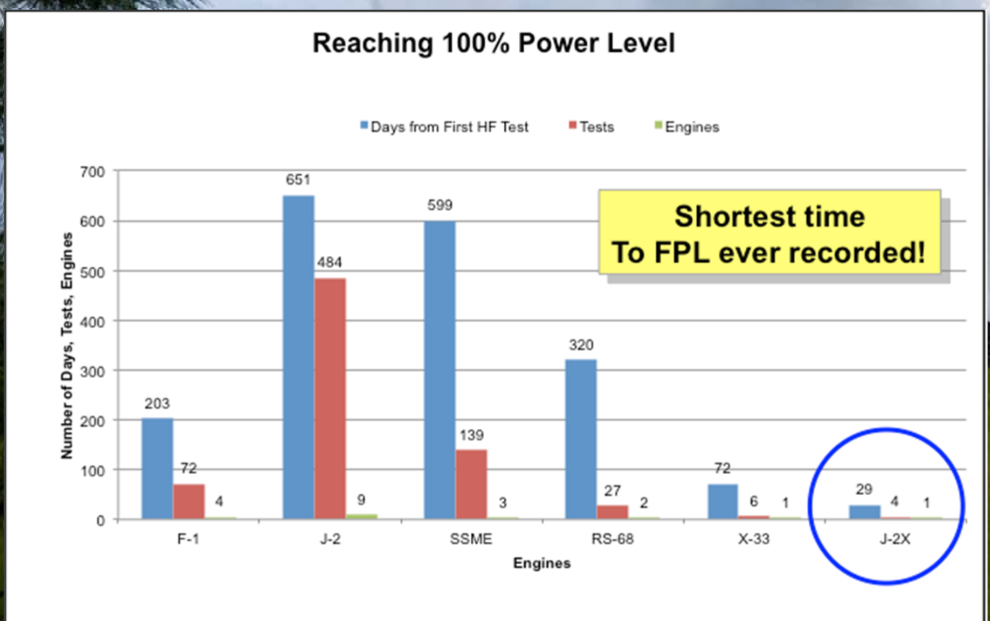


♦ Cycle	Gas Generator
♦ Thrust, vac (klbs)	294 (285K*)
♦ Isp, vac (sec)	448 (436*)min
♦ Pc (psia)	1,337
♦ MR	5.5
♦ AR	92 (59*)
♦ Weight (lbm)	5,450 max
♦ Secondary Mode MR	4.5
♦ Secondary Mode PC	~82%
♦ Restart	Yes
♦ Operational Starts	8
♦ Operational Seconds	2,600
♦ Length (in), Max	185
♦ Exit Dia.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

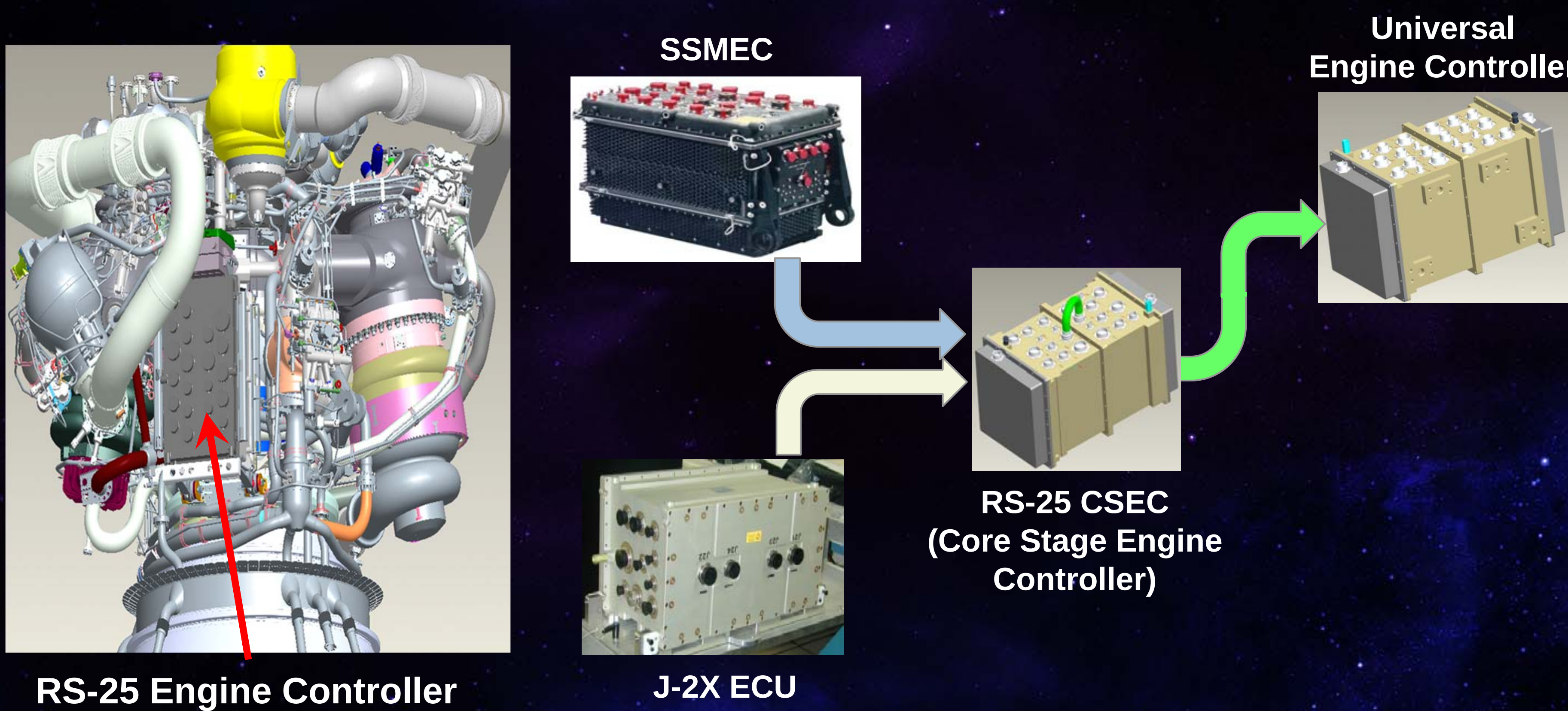


Test 1 July 7th - Chill
Test 2 July 14th - 1.9s, Ignition
Test 3 July 26th - 3.7s, 103% PL
Test 4 Aug 5th - 7.0s, 100% PL
Test 5 Aug 17th - 32.3s, 103% PL
Test 6 Sep 28th - 40.0s, 103% PL
Test 7 Oct 25th – 140.0s, 100% PL
Test 8 Nov 9th – 500.0s, 100%PL

J-2X Engine Inventory Manufacturing and Assembly Status

Assembly Complete and In Testing	Ready to Assemble	In Manufacturing
 E10001	 E10002  E10003	 E10004  E10005

RS-25 Engine Controller Overview

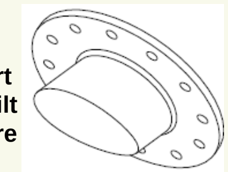


Selective Laser Melting Road to Flight

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

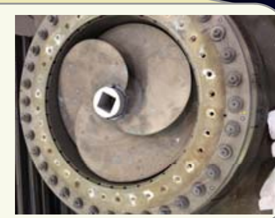
Fly SLM components in 2017.

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



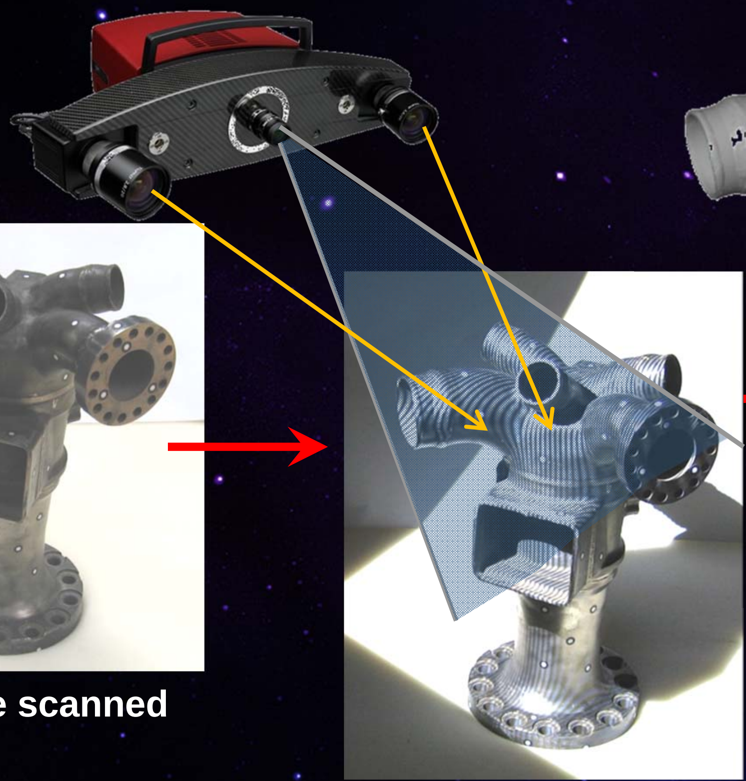
✓ Activity Completed

✓ Activity in work

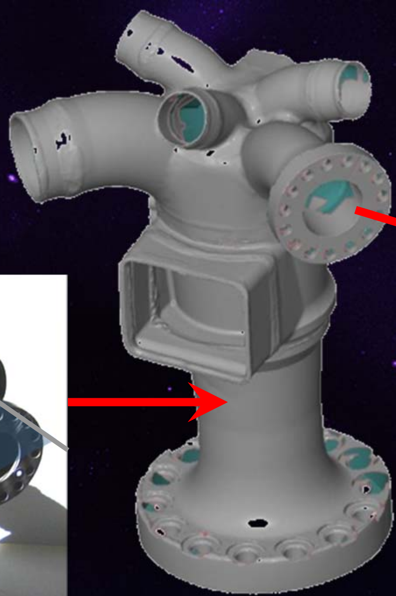
Structured Light

RS25 Mixer

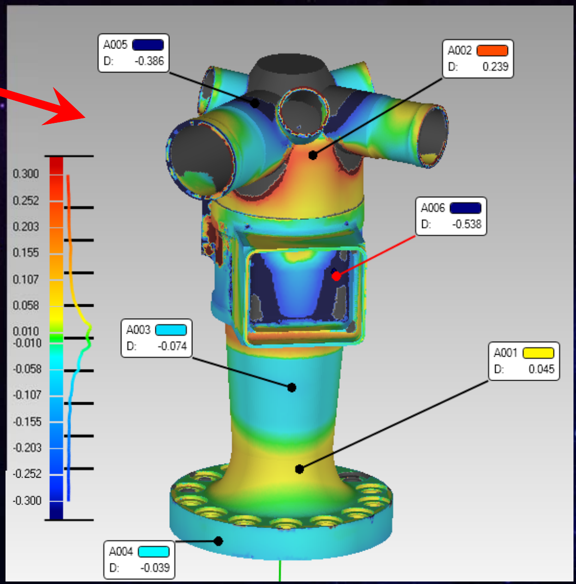
Part to be scanned



Scanning



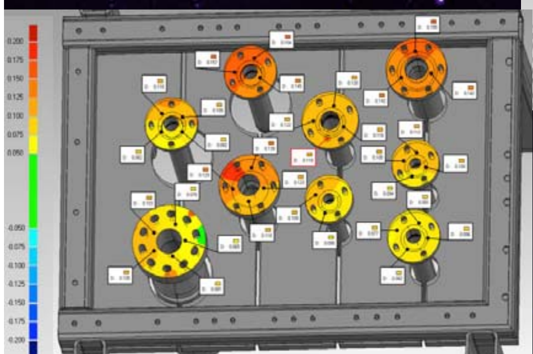
Raw Scan Data



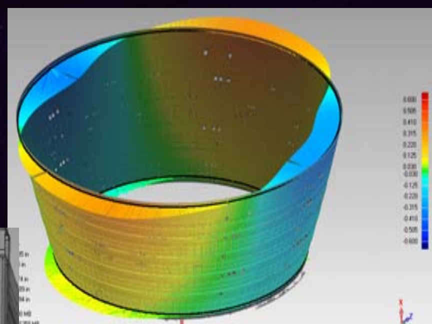
Analysis of Data,
CAD Comparison

SLS Structured Light Examples

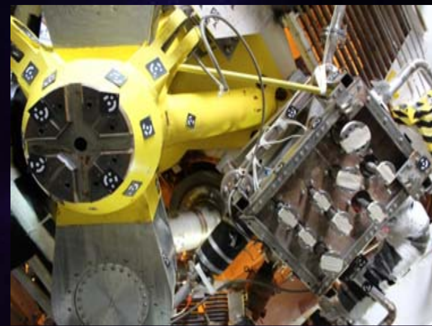
Engine Interface Adjustment

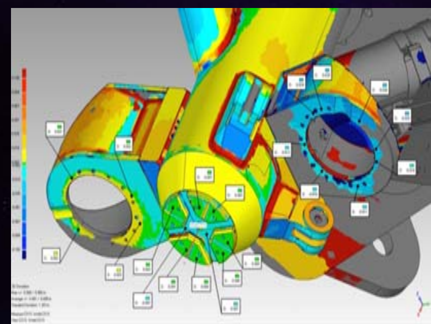


J-2X Extension

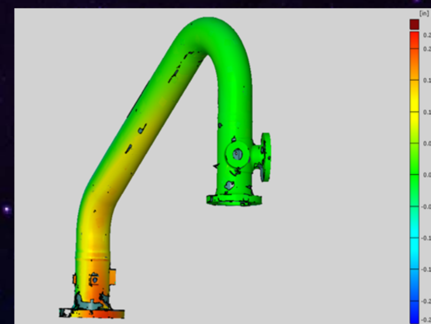


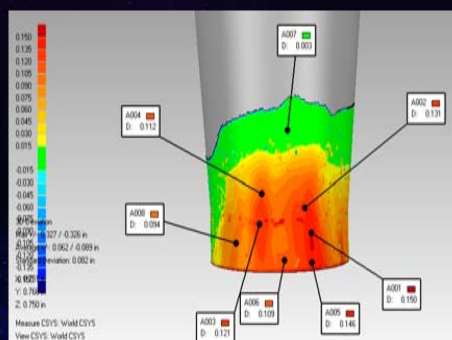
J-2X Engine Integration



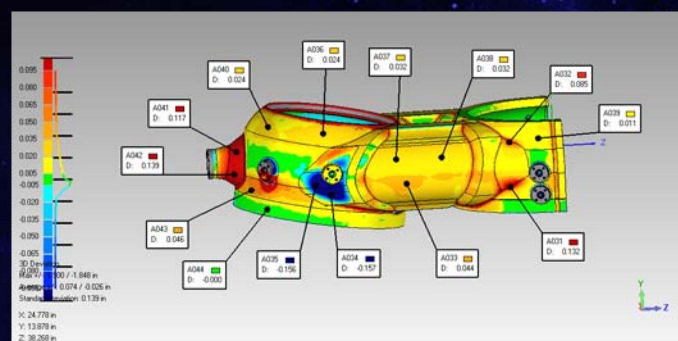


J-2X Duct Alignment





ASI Erosion Mapping



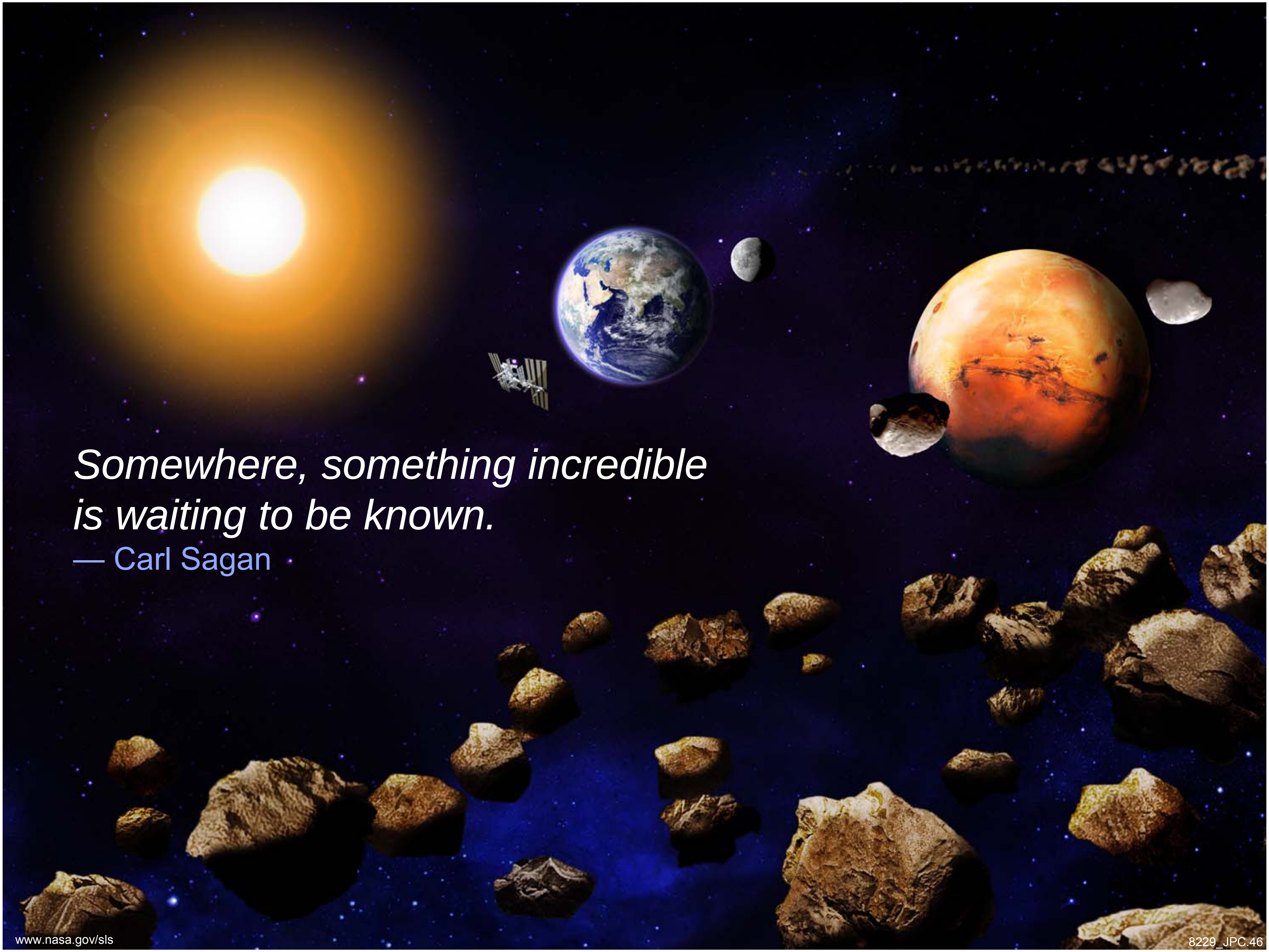
RS25 Powerhead Reverse Engineering

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
www.nasa.gov/sls
8229_JPC.46

For More Information

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