National Aeronautics and Space Administration

NASA Space Launch System (SLS) Development: *Challenges and Solutions*

Garry M. Lyles
SLS Chief Engineer
NASA Marshall Space Flight Center

July 15, 2013

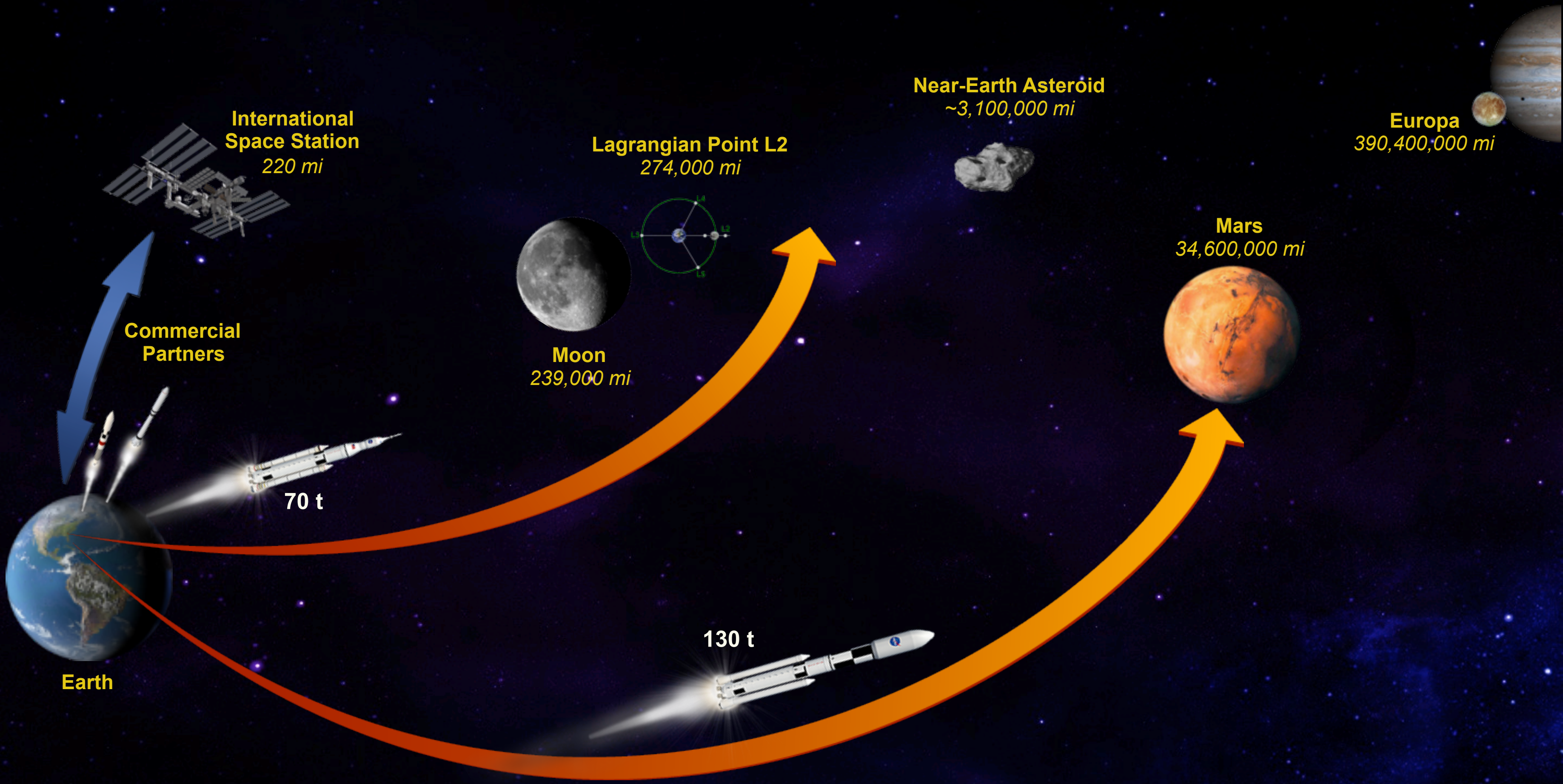
Space Launch System

www.nasa.gov/sls

Agenda

- Opening Remarks
- RS-25 Engine
- Core Stage
- Booster
- Interim Cryogenic Propulsion System

The Future of Exploration



International Space Station
220 mi

Lagrangian Point L2
274,000 mi

Near-Earth Asteroid
~3,100,000 mi

Europa
390,400,000 mi

Commercial Partners

Moon
239,000 mi

Mars
34,600,000 mi

70 t

130 t

Earth

The Space Launch System [will] be the backbone of its manned spaceflight program for decades. It [will] be the most powerful rocket in NASA's history…and puts NASA on a more sustainable path to continue our tradition of innovative space exploration.

President Obama's Accomplishments for NASA
May 22, 2012

SLS Driving Objectives

Safe

- Human-rated to provide safe and reliable systems
- Protecting the public, NASA workforce, high-value equipment and property, and the environment from potential harm

Affordable

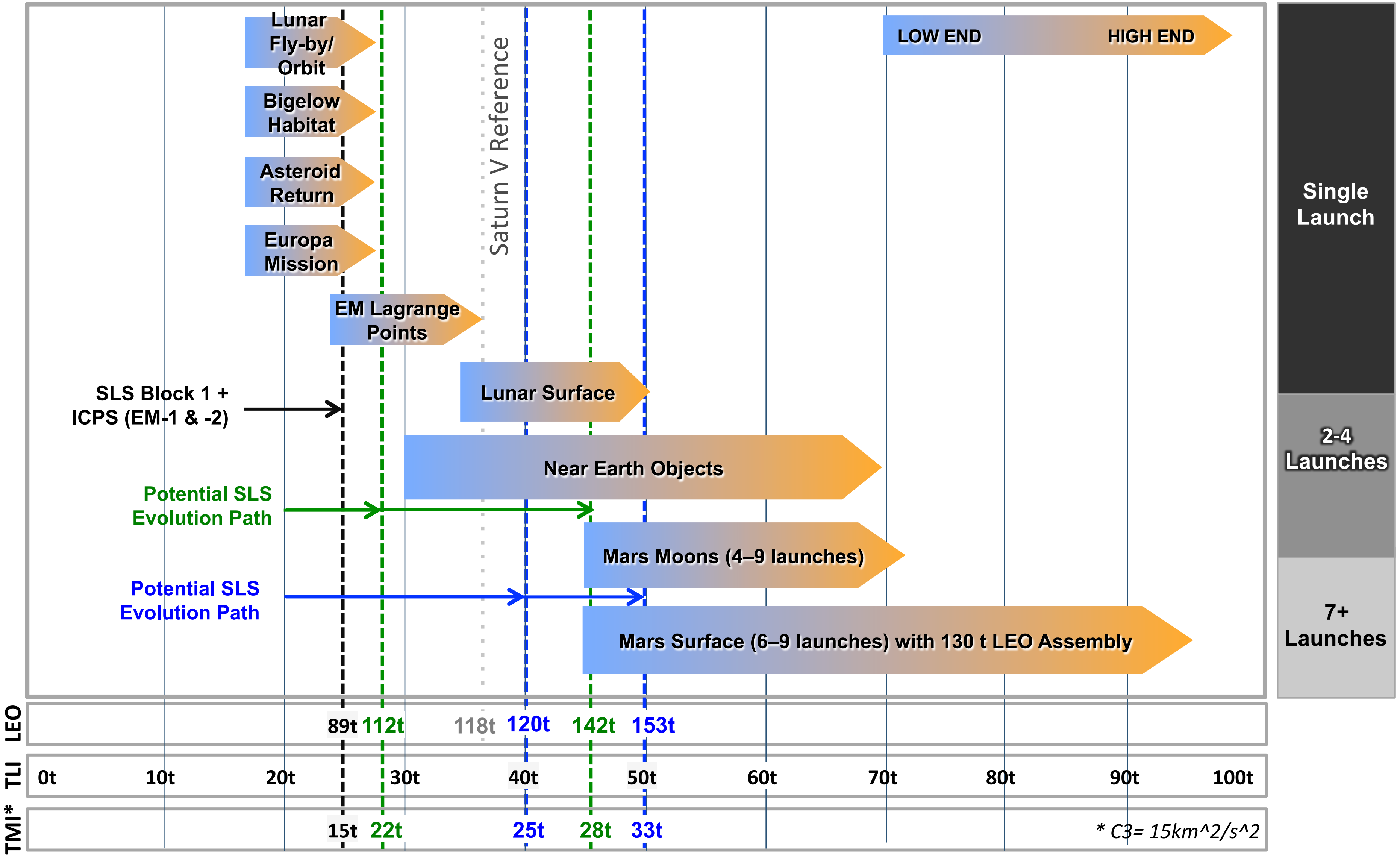
- Maximum use of common elements and existing assets, infrastructure, and workforce
- Constrained budget environment
- Competitive opportunities for affordability on-ramps

Sustainable

- Initial capability: 70 metric tons (t), 2017–2021
  - Serves as primary transportation for Orion and human exploration missions
- Evolved capability: 105 t and 130 t, post-2021
  - Offers large volume for science missions and payloads
  - Reduces trip times to get science results faster
  - Minimizes risk of radiation exposure and orbital debris impacts

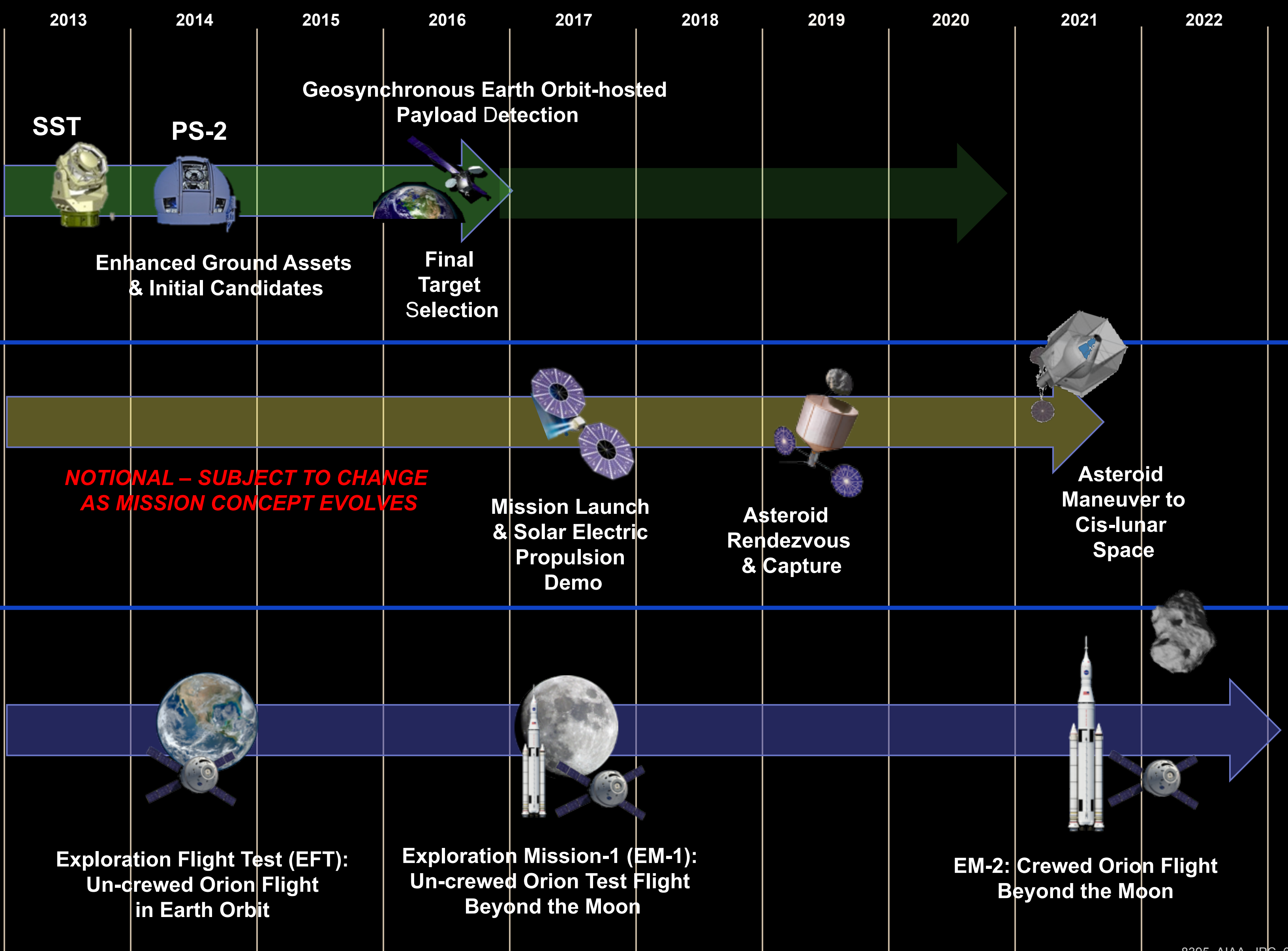
Platform for Missions Beyond Earth's Orbit

Potential SLS Mission Capture and Evolution



Single Launch Equivalent Gross Capability

SLS Launch Schedule



2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022

Asteroid Detection, Characterization, & Selection Segment

SST

PS-2

Geosynchronous Earth Orbit-hosted Payload Detection

Enhanced Ground Assets & Initial Candidates

Final Target Selection

Asteroid Redirection Segment

NOTIONAL – SUBJECT TO CHANGE AS MISSION CONCEPT EVOLVES

Mission Launch & Solar Electric Propulsion Demo

Asteroid Rendezvous & Capture

Asteroid Maneuver to Cis-lunar Space

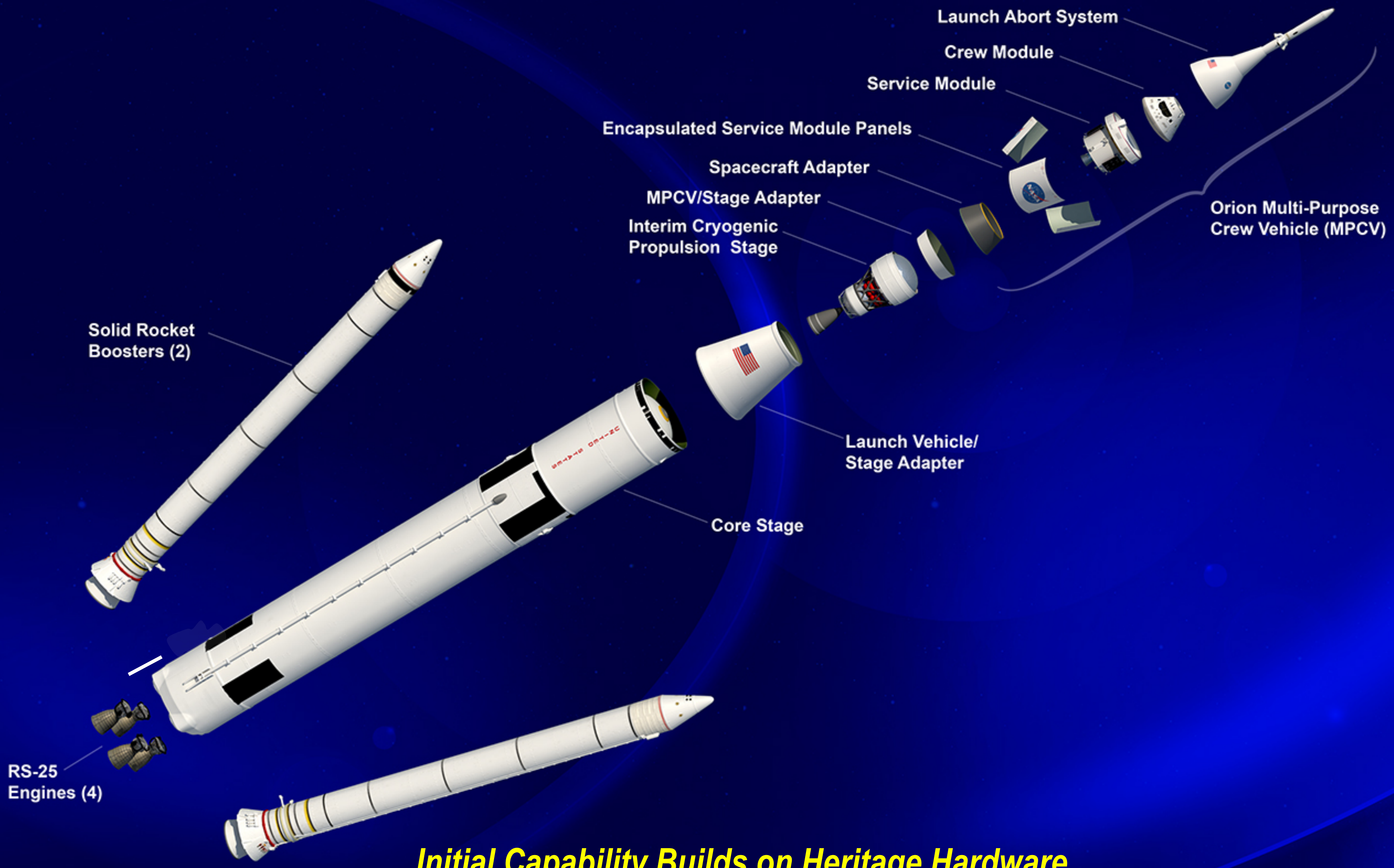
Orion & SLS Crewed Asteroid Exploration Segment

Exploration Flight Test (EFT): Un-crewed Orion Flight in Earth Orbit

Exploration Mission-1 (EM-1): Un-crewed Orion Test Flight Beyond the Moon

EM-2: Crewed Orion Flight Beyond the Moon

70 Metric Ton Expanded View



Initial Capability Builds on Heritage Hardware

Heritage Hardware Considerations

Contractual

- Existing contracts may provide a fast start
- Contracts clearly define scope
- Hardware capabilities and people/processes are typically intertwined with contractual considerations

Hardware

- Heritage hardware comes with all of the heritage capabilities
- Heritage hardware also comes with all of the heritage limitations

People/Processes

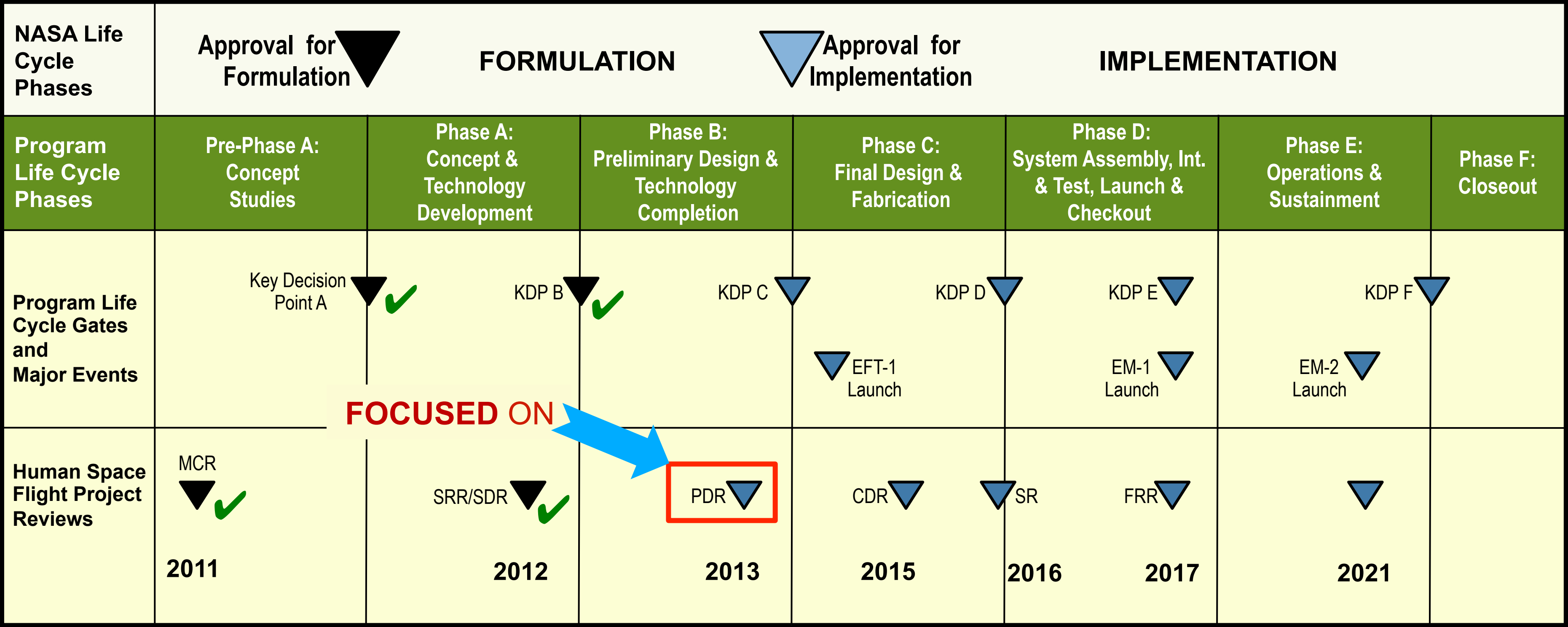
- Capabilities of heritage hardware typically tightly coupled with heritage processes
- Heritage processes are often tightly coupled with the people operating the processes

Cost

- Appropriate usage of heritage hardware, existing assets and infrastructure, and existing contracts is an important part of the overall approach for affordability
- Heritage hardware typically comes with legacy costs

Technical integration focused on interfaces (structural, electrical, and organizational) between individually procured hardware elements

The Road to First Flight in 2017



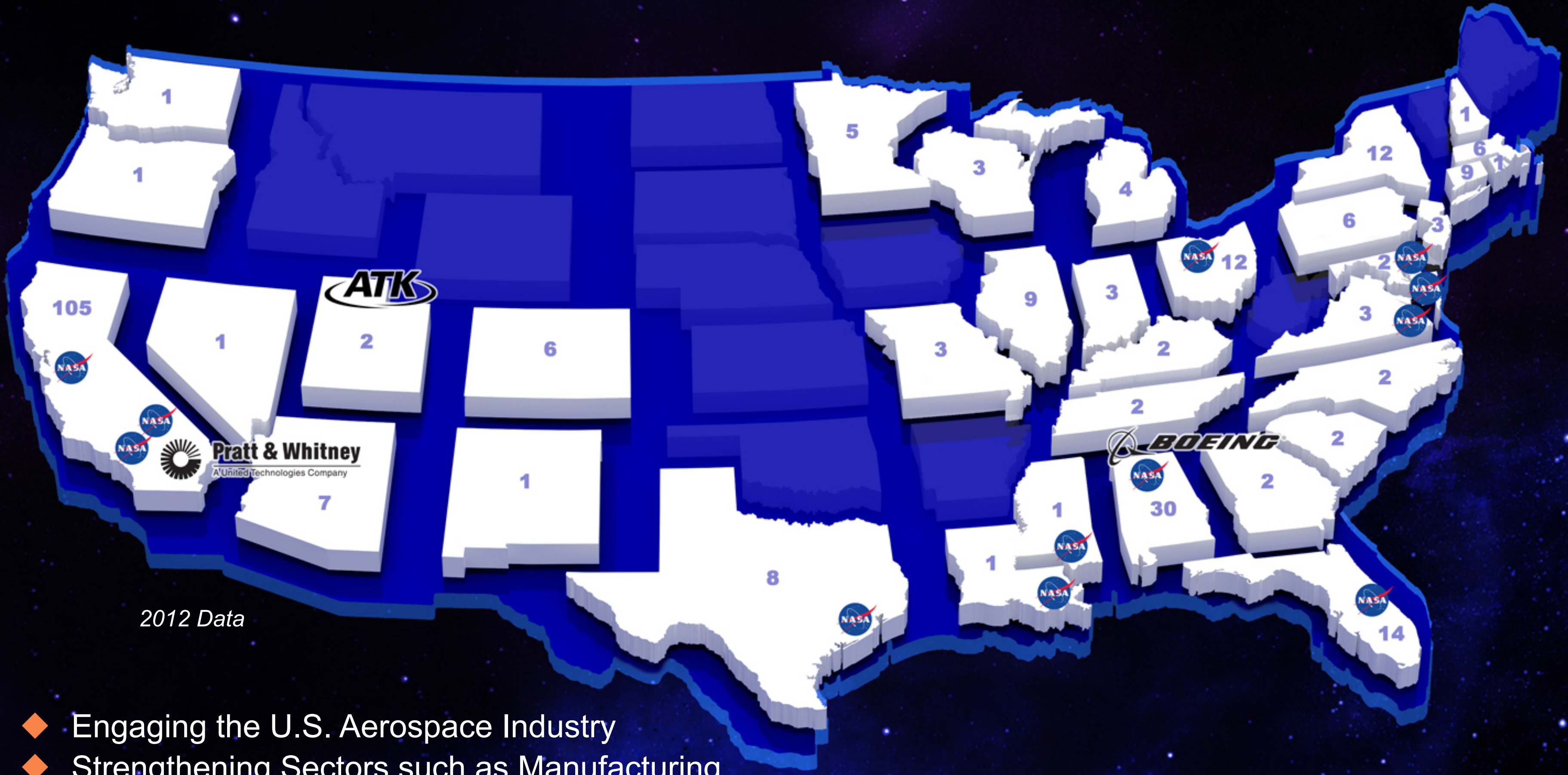
NASA Life Cycle Phases	Approval for Formulation ▼	FORMULATION		▽ Approval for Implementation	IMPLEMENTATION		
Program Life Cycle Phases	**Pre-Phase A: Concept Studies**	**Phase A: Concept & Technology Development**	**Phase B: Preliminary Design & Technology Completion**	**Phase C: Final Design & Fabrication**	**Phase D: System Assembly, Int. & Test, Launch & Checkout**	**Phase E: Operations & Sustainment**	**Phase F: Closeout**
Program Life Cycle Gates and Major Events	Key Decision Point A ▼ ✓	KDP B ▼ ✓	KDP C ▼	KDP D ▼ ▼ EFT-1 Launch	KDP E ▼ EM-1 Launch ▼	KDP F ▼ EM-2 Launch ▼	
Human Space Flight Project Reviews	MCR ▼ ✓ **2011**	SRR/SDR ▼ ✓ **2012**	PDR ▼ **2013**	CDR ▼ **2015**	▼ SR **2016** FRR ▼ **2017**	▼ **2021**	

[A] monumental effort … has gone into this Program….
I don't think anyone would have thought in September [2011] that this Program might be this far so fast.

LeRoy Cain, Chair
Standing Review Board
June 29, 2012

CDR: Critical Design Review	MCR: Mission Concept Review
EM: Exploration Mission	PDR: Preliminary Design Review
EFT: Exploration Flight Test	SIR: System Integration Review
FRR: Flight Readiness Review	SDR: System Definition Review
KDP: Key Decision Point	SRR: System Requirements Review

SLS Partnerships Nationwide



2012 Data

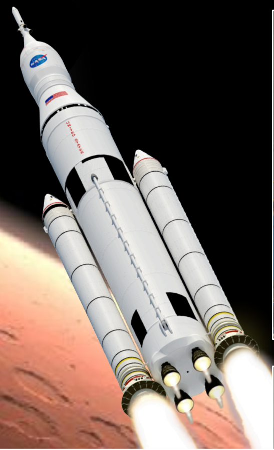
- Engaging the U.S. Aerospace Industry
- Strengthening Sectors such as Manufacturing
- Advancing Technology and Innovation

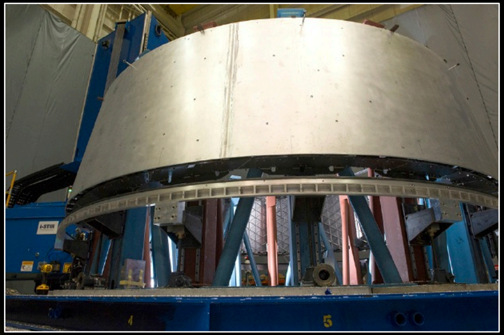
208 Subcontracts in 28 States

NASA's Space Launch System

On Course for First Flight in 2017

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





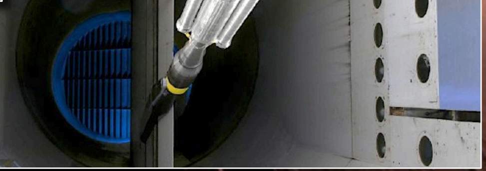
Spacecraft & Payload Integration
Produced Multi-Purpose Crew Vehicle Stage Adapter for 2014 Exploration Flight Test at the Marshall Space Flight Center (Feb 2013)

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

Preparing segmented ring tool for Core Stage construction at the Michoud Assembly Facility in New Orleans

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

Core Stage
Produced Core Stage test panel at AMRO Fabricating Corp. in South El Monte, CA (Dec 2012)



Systems Engineering & Integration
Tested buffet model in Langley Research Center's Transonic Dynamics Wind Tunnel (Nov 2012)

SAFE, AFFORDABLE, SUSTAINABLE

Powering the Future of Exploration

National Aeronautics and Space Administration

RS-25 Engine Development Challenges and Solutions

Katherine P. Van Hooser
SLS Engines Chief Engineer
NASA Marshall Space Flight Center
Doug Bradley
RS-25 Core Stage Engine Chief Engineer
Aerojet Rocketdyne

July 15, 2013

Space Launch System

Agenda

- Opening Remarks
- **RS-25 Engine**
- Core Stage
- Booster
- Interim Cryogenic Propulsion System

- **Challenge:** Long Term Storage
  Solutions: Transfer to Stennis Space Center; Identify/optimize storage options
- **Challenge:** Heritage engine Controller Unit incompatible with new vehicle
  Solutions: Design new controller; leverage J-2X design
- **Challenge:** Higher Liquid Oxygen (LOX) inlet pressure
  Solutions: Modify engine; Limit maximum pressure; Modify start sequence
- **Challenge:** Lower LOX temperatures
  Solutions: Add heat; Reduce pre-start bleed flows; Modify start sequence

NASA's Space Launch System RS-25 Development Challenges and Solutions

- **RS-25 Support to SLS**
  - Proven
  - Flexible
  - Affordable
- **Heritage engine integration into new vehicle**
  - Interfaces, environments – external and internal
- **Specific challenges and solutions**
  - Asset management
  - Obsolescence - controller
  - Integration – LOX inlet conditions
- **Accomplishments**

RS-25/Space Shuttle Main Engine

Proven – Flexible - Affordable

- **Proven safety and reliability**
- **Man-rated**
- **Versatile high performance capability demonstrated**
- **Significant hardware availability at end of program**
  - 16 flight engines
  - 2 development engines

Selected for Space Launch System Core Stage

RS-25 Asset Management

- **SLS mission assessment**
  - Power level capability demonstrated in Space Shuttle Main Engine (SSME) program
  - Life limits reassessed, updated to meet SLS mission requirements

- **Challenge**: Long term storage
  - Protect from damage, deterioration

- **Solutions**
  - Transferred engines from Kennedy Space Center (KSC) to Stennis Space Center (SSC)
  - Options for storage identified and optimized
    - Containers
    - Bags
    - Purges
    - Monitoring

Engines at KSC at End of Shuttle Program

Engines at SSC

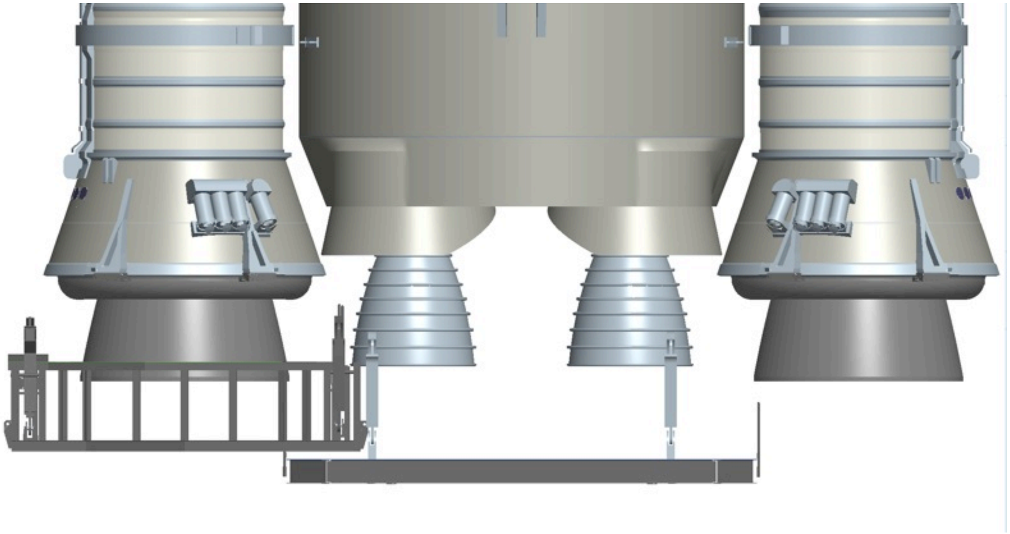
Engine Integration into Vehicle

- **Heritage engine designed for Shuttle must be integrated into SLS vehicle**

- **Physical interfaces**
  - Mechanical interfaces: Defined and coordinated with Stages Element
  - Electrical interfaces: Engine controller in work

- **Exterior environments**
  - Aft compartment conditions
  - Reduced distance between Booster plume and RS-25 nozzles

- **Internal environments**
  - Gases, hydraulics: Defined
  - Propellant inlet conditions



Engine Controller Unit (ECU)

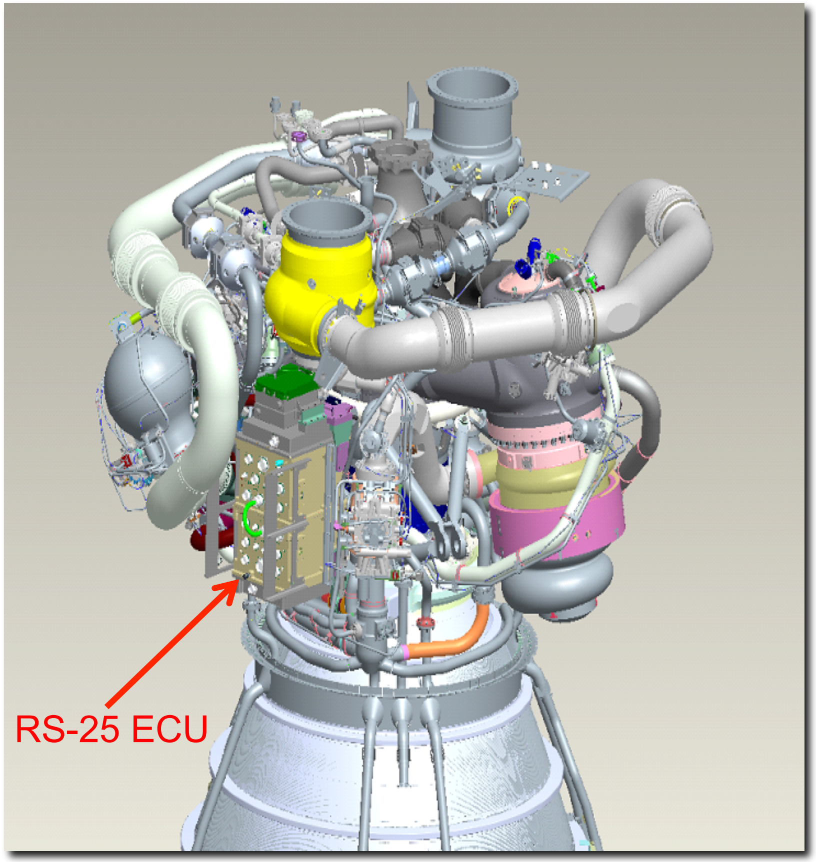
ECU function

- 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

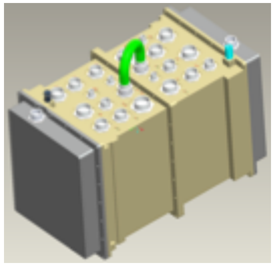
Solutions

- Design new controller rather than adapt old
- Leverage J-2X design for "universal controller"



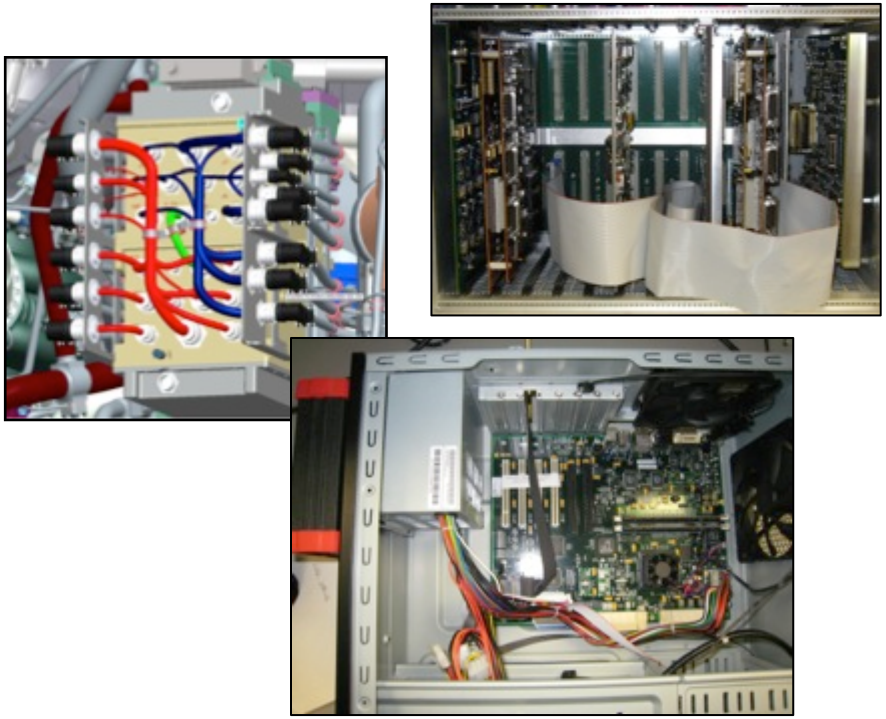
Engine Controller Unit (ECU) (Continued)

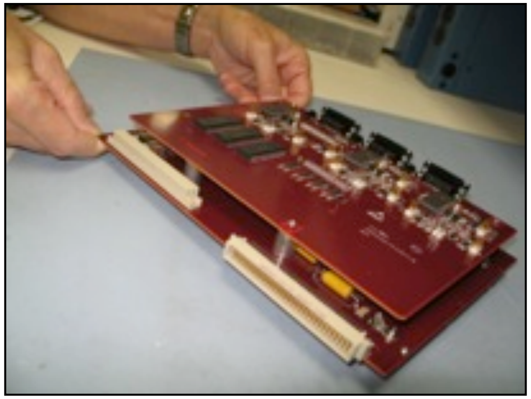
SSME
Engine Controller Unit



RS-25 ECU
Basic design supports
RS-25 and J-2X

J-2X Engine Controller Unit

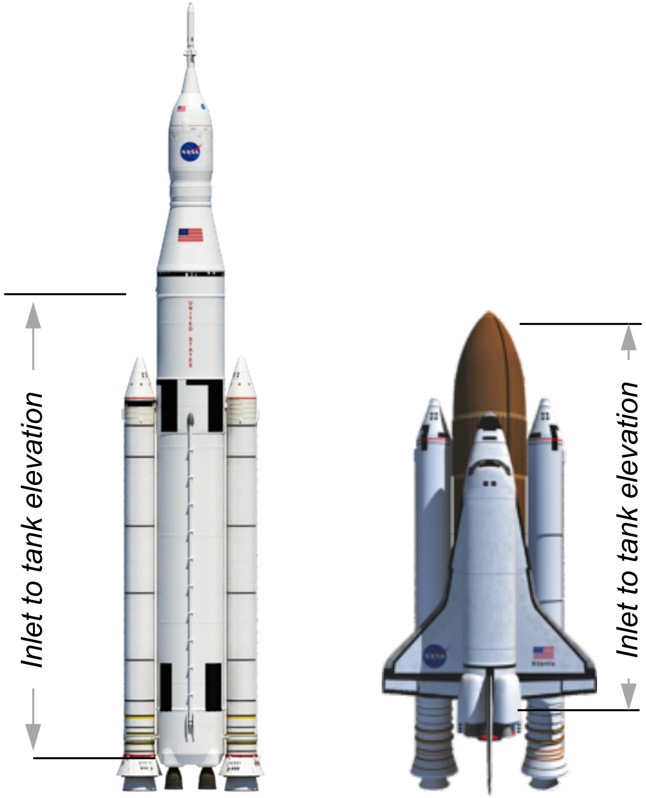




◆ Hardware Critical Design Review (CDR)	May 2013 √
◆ Software Preliminary Design Review (PDR)	June 2013 √
◆ ECU Demo #2 / Operational Flight Program (OFP) functionality	Dec 2013
◆ Software CDR	Dec 2013
◆ **First Engineering Controller (EM1)**	**Mar 2014**

Propellant Inlet Conditions

- **Challenge:** Higher LOX inlet pressure
  - Elevation and configuration of vehicle
- **Solutions**
  - Modify engine to adapt to pressure
  - Limit maximum pressure with mission profile changes
  - Modify start sequence
- **Status**
  - Leverage SSME experience to establish start sequence
  - Verify start and mainstage characteristics during ground testing

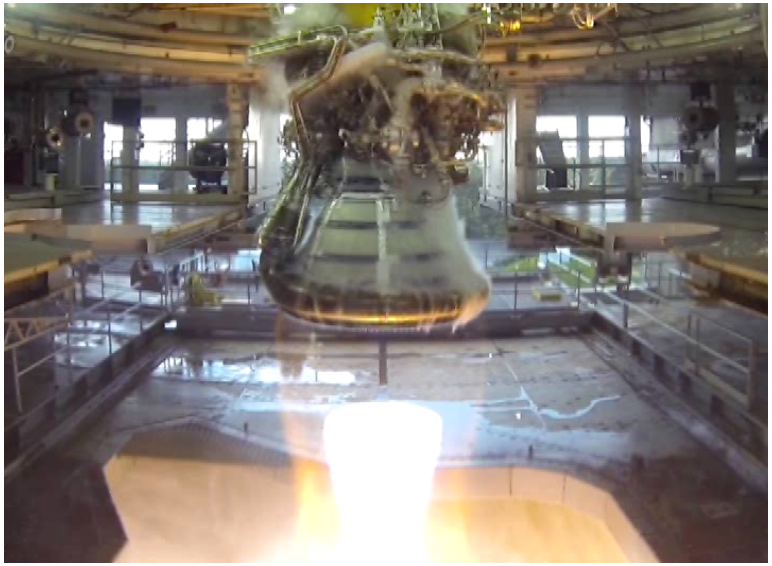


Propellant Inlet Conditions (Continued)

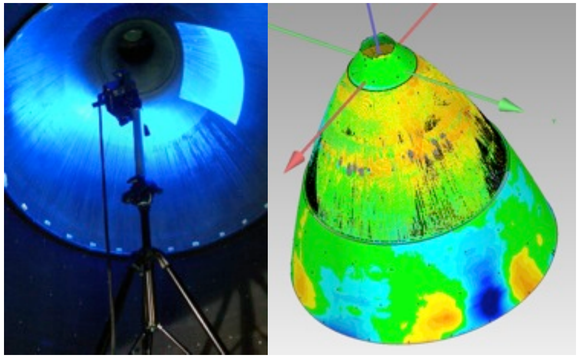
- **Challenge:** Lower LOX temperatures
  - Configuration of vehicle
  - Potential for damage induced by temperature spikes during start

- **Solutions**
  - Add heat
  - Reduce pre-start bleed flows
  - Modify start sequence
- **Status**
  - Leverage SSME experience to establish bleed flows and start sequence
  - Engine and vehicle experts developing combined solution
  - Verify start characteristics during ground testing

Top Accomplishments - Engines



1st Gimballing Test for J-2X
June 14, 2013



Structured light used in various
applications to reduce
development time

J-2X has completed 50 tests on 2 engines
and 2 powerpacks as of June 20, 2013

RS-25 Ready to Support Vehicle
Preliminary Design Review
June, 2014

Core Stage Challenges and Solutions

Mike Wood
SLS Chief Engineer
Boeing
July 15, 2013

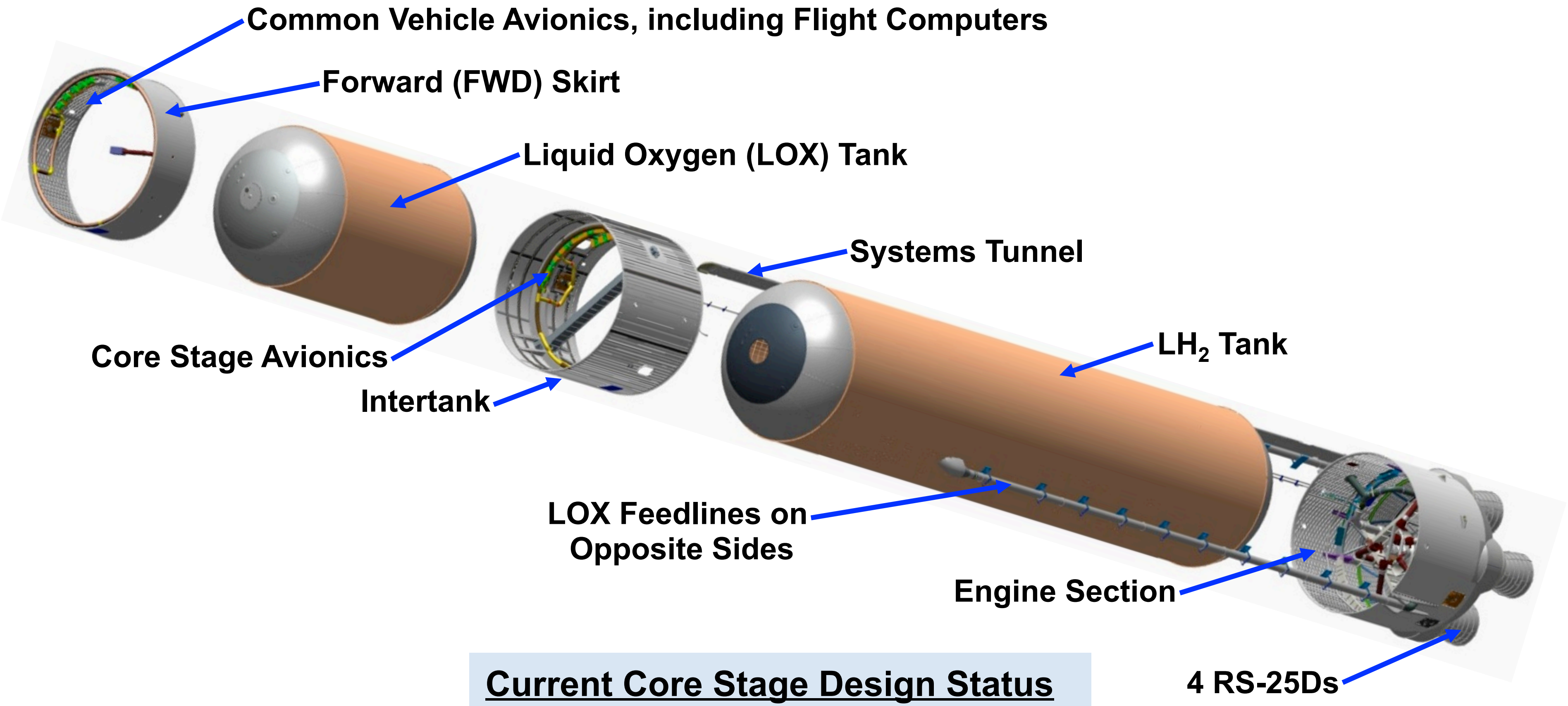
Space Launch System

Agenda

- Opening Remarks
- RS-25 Engine
- **Core Stage**
- Booster
- Interim Cryogenic Propulsion System

- **Challenge:** Vibroacoustic environment
  Solutions: Direct part re-use; Design re-use
- **Challenge:** Shock and random vibration loads
  Solutions: Direct part re-use; Design re-use
- **Challenge:** Engine interface Control Document GO_2 interface temperature; maximum interface pressure
  Solutions: Design re-use

SLS Core Stage Development On Track for Mid-2014 Critical Design Review



Current Core Stage Design Status

- Post-PDR (Dec 2012)
- Drawing release well underway
- Leveraging heritage components
  - Atlas, Delta, Shuttle
  - Cost and schedule opportunities
- Major tooling nearing completion

Component Re-Use Reduces Technical Risk Provides Cost & Schedule Benefits

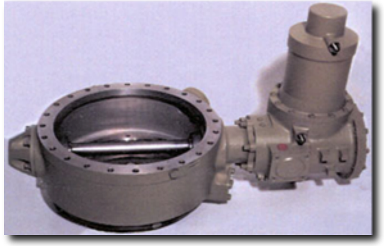
- **Core stage propulsion design based heavily on heritage programs**
  - LOX/LH_2 Subsystems
    - Atlas, Delta, Shuttle Heritage
  - Gaseous Oxygen (GO_2)/Gaseous Hydrogen (GH_2) Pressurization Systems
    - Delta Heritage
  - Pneumatic Systems
    - Delta, Shuttle Heritage

- **Leveraging analytical and heritage design strengths to develop subsystem design**

- **New rocket design and environments create additional challenges**


MPS Shuttle Prevalve


MPS Shuttle Pneumatic Regulator


Shuttle Fill & Drain Valve


Delta IV Pressurization Solenoid Valve


Shuttle Thrust Vector Control Actuator

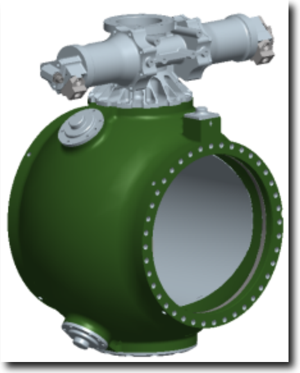

Shuttle Hydraulic Recirculation Pump

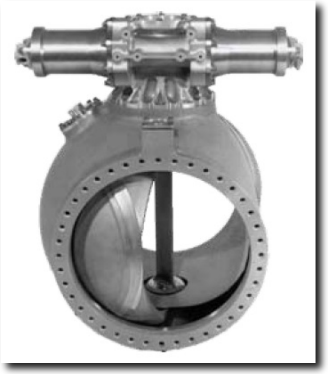
Component Reuse Reduces Technical Risk
LOX Prevalve Opportunity Testing Underway

- **Reuse Opportunity**
  - Shuttle LOX Prevalve
    - Direct part reuse
    - Design reuse

- **Challenge:** Vibroacoustic environment

- **Solutions**
  - Direct part reuse
    - Development test to validate direct part reuse
  - Design reuse
    - Structurally enhanced prevalve


Design Reuse

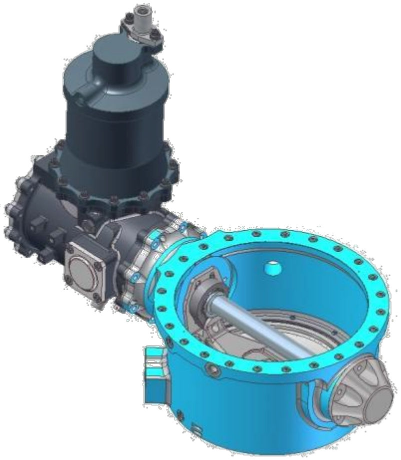

Direct Part Reuse (Testing In Work)


Prevalve with Test Plate

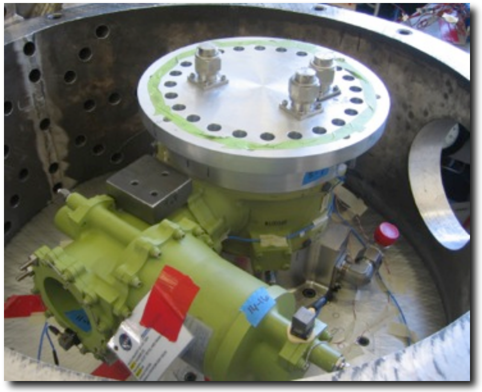

Prevalve Bench Testing on Common Cryo Test Stand

Component Reuse Reduces Technical Risk
LH_2/LOX Fill and Drain Valve

- **Reuse Opportunity**
  - Shuttle LH_2/LOX Fill & Drain Valve
    - Direct part reuse
    - Design reuse
- **Challenge:** Shock and random vibration loads
- **Solutions**
  - Direct part reuse
    - Shock testing to higher SLS g-levels
    - Random vibration testing to SLS levels
    - Increase proof pressure testing
  - Design reuse
    - More robust valve body for design reuse



LH_2/LOX Fill & Drain Valve



Fill & Drain Valve Test Setup

Component Reuse Reduces Technical Risk Tank Pressurization Valve (TPV)

- **Reuse Opportunity**
  - Delta IV Tank Pressurization Valve (TPV)
    - Design reuse
- **Challenges**
  - Engine Interface Control Document (ICD) GO_2 interface temperature
  - Maximum interface pressure
- **Solutions**
  - Design reuse
    - Seal material thermal and pressure testing
    - Non-metallic to metallic materials
    - Fixed orifice

Delta IV Pressurization Solenoid Valve

SLS Core Stage On Track for 2017 Launch On-Cost, Ahead of Schedule, On-Target

Michoud Assembly Facility

Gore and Dome Weld Tools

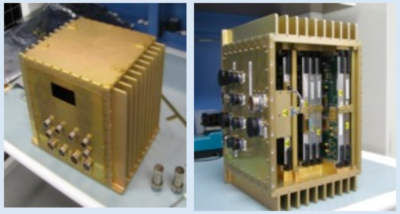
Segmented Ring Tool

Vertical Weld Center

Milestone Reviews

Early Completion of SRR/SDR and PDR

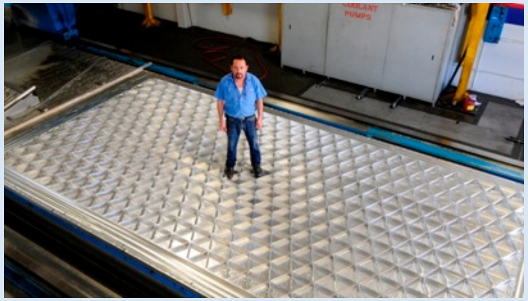
Avionics



Flight Computers

Lithium Ion Battery

Structures



Barrel Panels

Propulsion

SLS Thrust Vector Control

National Aeronautics and Space Administration

Booster Development Challenges and Solutions

Ellis M. (Mat) Bevill
Boosters Deputy Chief Engineer
NASA Marshall Space Flight Center
Dale B. Nielsen
SLS Deputy Chief Engineer
ATK Space Systems

July 15, 2013

Space Launch System

Agenda

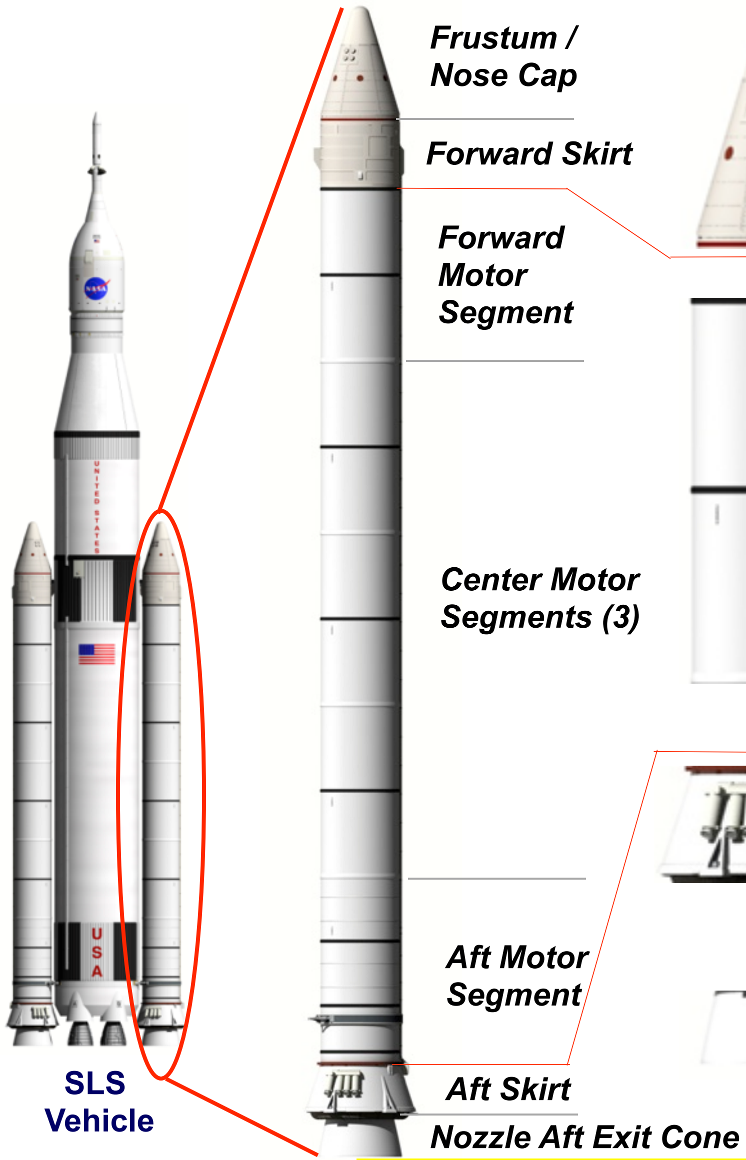
- Opening Remarks
- RS-25 Engine
- Core Stage
- **Booster**
- Interim Cryogenic Propulsion System

- **Challenge:** SLS loads at Forward Separation Bolt exceed heritage loads
  Solution: Separation bolt modified
- **Challenge:** SLS Core Stage required attach ring movement 240 inches aft
  Solutions: Tooling, processes, and non-structural hardware modifications
- **Challenge:** Threat of Booster Separation Motor (BSM) seal debris to Core Stage Engines
  Solutions: Utilize heritage seals from forward BSMs
- **Challenge:** Nozzle After Exit Cone Joint closeout labor intensive, non-verifiable, and uses obsolete materials
  Solutions: Replace backfill thermal barrier with thermal barrier O-ring
- **Challenge:** SLS program cost reductions
  Solutions: Multiple value stream mapping initiatives

Future Challenges/Solutions:

- **Challenge:** Ascent and liftoff loads reduce forward skirt safety factors
  Solutions: Evaluate skirt modification options and structural testing to failure
- **Challenge:** Acoustic load levels may exceed capability of avionics boxes
  Solutions: Box isolation, relocation, additional testing options
- **Challenge:** SLS thermal and structural ignition pressure loads exceed heritage thermal curtain capabilities
  Solutions: Test, analysis, and potential curtain modification

SLS Booster Configuration (Block 1)



Frustum / Nose Cap

Heritage:

- Structures
- Booster Separation Motors (BSMs)

Eliminated: Recovery System (Parachutes, Pyros, Sensors, etc.)

Forward Skirt

Heritage: Structures

New / Modified: Avionics

Modified: Separation Bolt

Forward Segment

Heritage: Structures

Propellant Grain:

- **Modified:** Reusable Solid Rocket Motor (RSRM)→Ares
- **No Change:** Ares→SLS

Center Segments

Heritage: Structures

Added Segment: RSRM→Ares

Propellant Inhibitor:

- **Modified:** RSRM→Ares
- **No Change:** Ares→SLS

Aft Segment

Heritage: Structures

Changed: Core Attach Location

Eliminated: Stiffener Stubs/Rings

Aft Skirt

Heritage:

- Structures
- BSMs
- Thrust Vector Control (TVC)

Modified: TVC Avionics

Nozzle Aft Exit Cone

Improved: KSC Joint

Larger/Extended:

- **Modified:** RSRM→Ares:
- **No Change:** Ares→SLS

Booster

Heritage

- Separation Pyros
- Thermal Protection System (TPS)

Simplified

- KSC Joint Closeout

Modified

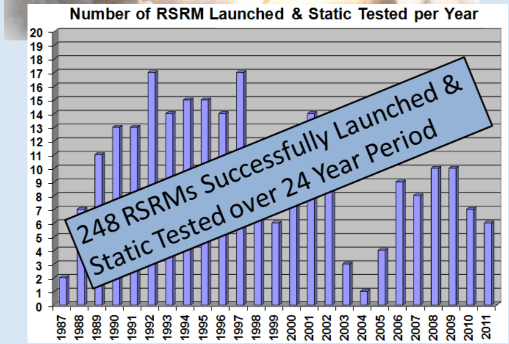
- Flight Safety System Pyros
- Systems Tunnel
- Cables

Heritage and Modified Hardware Utilized for Optimal Design

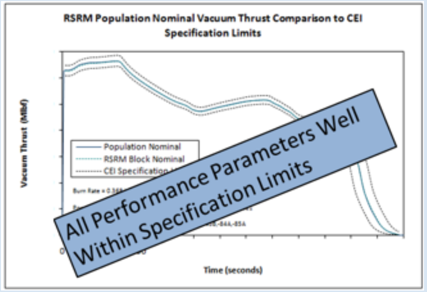
SLS Booster Performance Confidence

Space Shuttle SRB

Extensive Flight & Static Test Motor Experience Base



248 RSRMs Successfully Launched & Static Tested over 24 Year Period

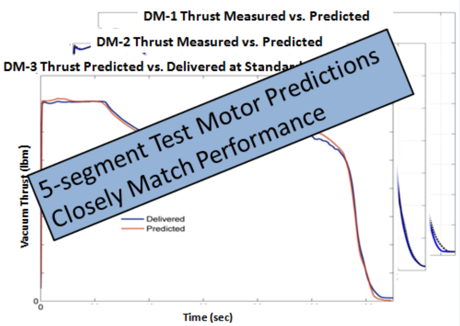


All Performance Parameters Well Within Specification Limits

Demonstrated Performance Consistency Over Life of Program

Three Successful 5-Segment Development Motor (DM) Static Tests Conducted

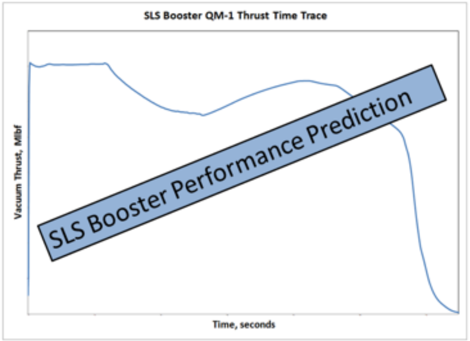
Ares 1st Stage



5-segment Test Motor Predictions Closely Match Performance

Excellent Prediction-to-Performance Correlation

SLS Booster



SLS Booster Performance Prediction

Assembly of Qualification Motor (QM) -1 Static Test

QM-1 & QM-2 Static Tests & Experience Base Provide High Confidence SLS Boosters Meet All SLS Vehicle Needs

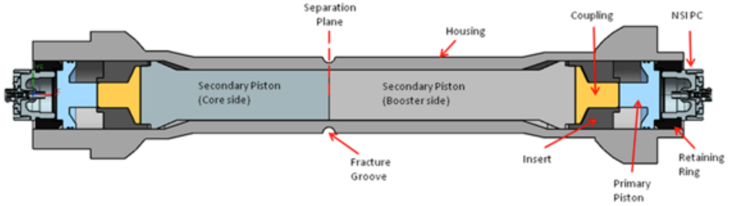
Design Challenges/Solutions: Loads & Configuration Driven

Forward Separation Bolt

Challenge: SLS loads at the Forward Separation Bolt exceed heritage Shuttle (STS) loads

Solution: Separation bolt modified to accommodate SLS loads

- Housing groove and pyrotechnic charge changes verified through testing

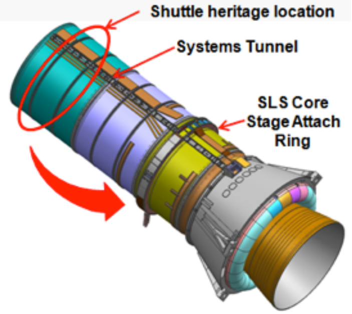


Core Attach Ring

Challenge: SLS Core Stage required attach ring movement 240 inches aft (from heritage Shuttle ET location)

Solution: Tooling, processing, and non-structural hardware modifications (system tunnel, linear shape charge, etc.)

- Changes demonstrated on pathfinder aft segment build



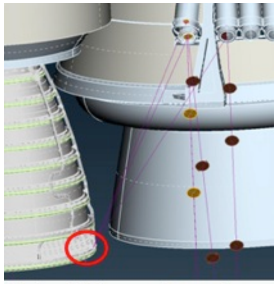
Aft Booster Separation Motors (BSMs)

Challenge: Threat of BSM seal debris impact to Core Stage Engines (at Booster separation)

Solution: Utilize (heritage) seals from forward BSMs.

- Forward BSM seal design does not liberate debris

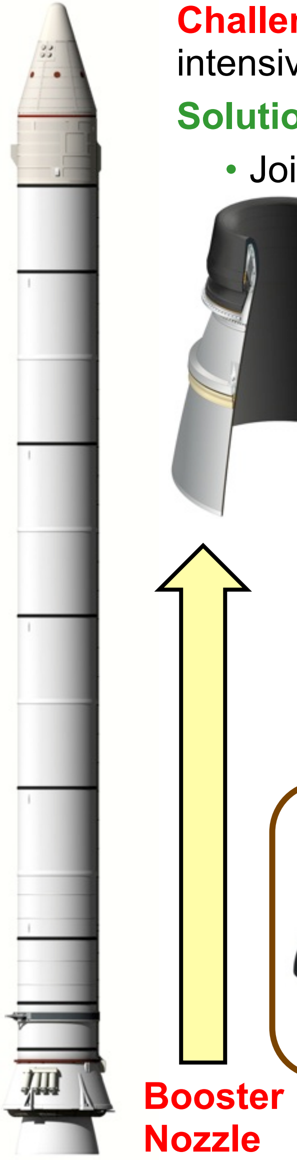
Forward BSM Heat Seal



Potential Impact Zone from Current Aft Heat Seal

Multiple Challenges Continue to be Successfully Addressed

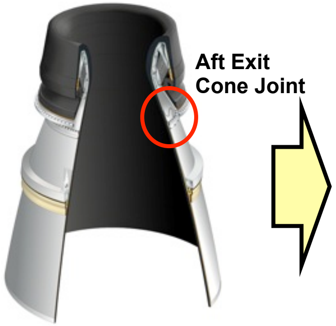
Design Challenges/Solutions: Improvement Opportunities

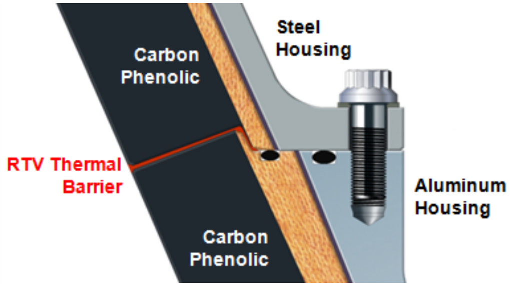


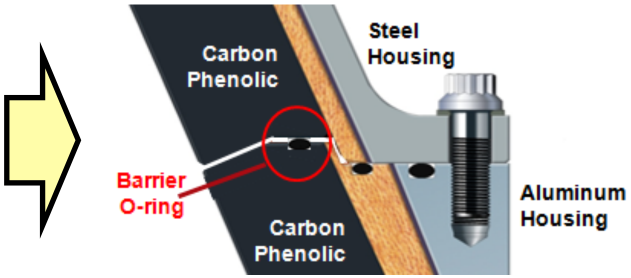
Challenge: Nozzle Aft Exit Cone Joint (mated at Kennedy Space Center (KSC)) closeout labor intensive, non-verifiable, and utilizes obsolete materials

Solution: Replace backfill thermal barrier with thermal barrier O-ring

- Joint design reliability increase with significant simplification of KSC closeout



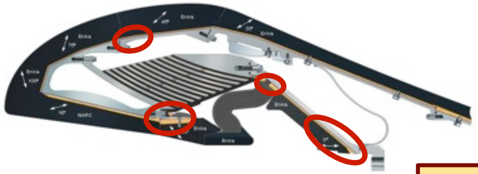


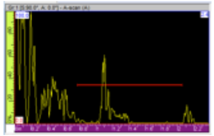


Challenge: SLS program to implement significant cost reductions over previous man-rated space flight programs

Solution: Multiple value stream mapping (VSM) initiatives result in ~46% reduction in SLS Booster production timeline

Nozzle Phenolic and Bondline Inspections





Practical Handling Improvements

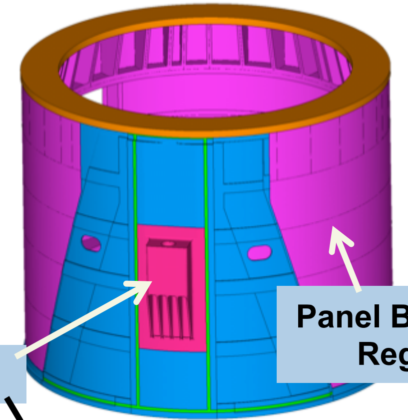
Relatively small implementation costs leading to substantial cost savings.

Multiple Improvement Opportunities Incorporated

Future Challenges: Loads Driven

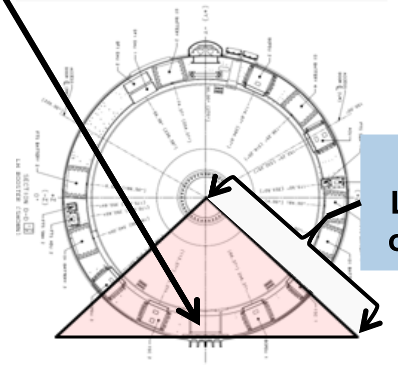
Challenge: Ascent and liftoff loads result in reduced forward skirt safety factors and potential thrust post yielding and/or panel buckling.

Solution: Evaluate skirt modification options and structural testing (to failure) for additional model correlation.



Challenge: Acoustic load levels may exceed capability of avionics boxes mounted near forward skirt thrust post.

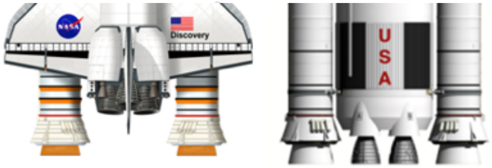
Solution: Box isolation, relocation, or additional testing options being evaluated.



Challenge: SLS thermal and structural (ignition pressure) loads exceed heritage thermal curtain capabilities.

Solution: Test, analysis, and potential curtain modification options in work.

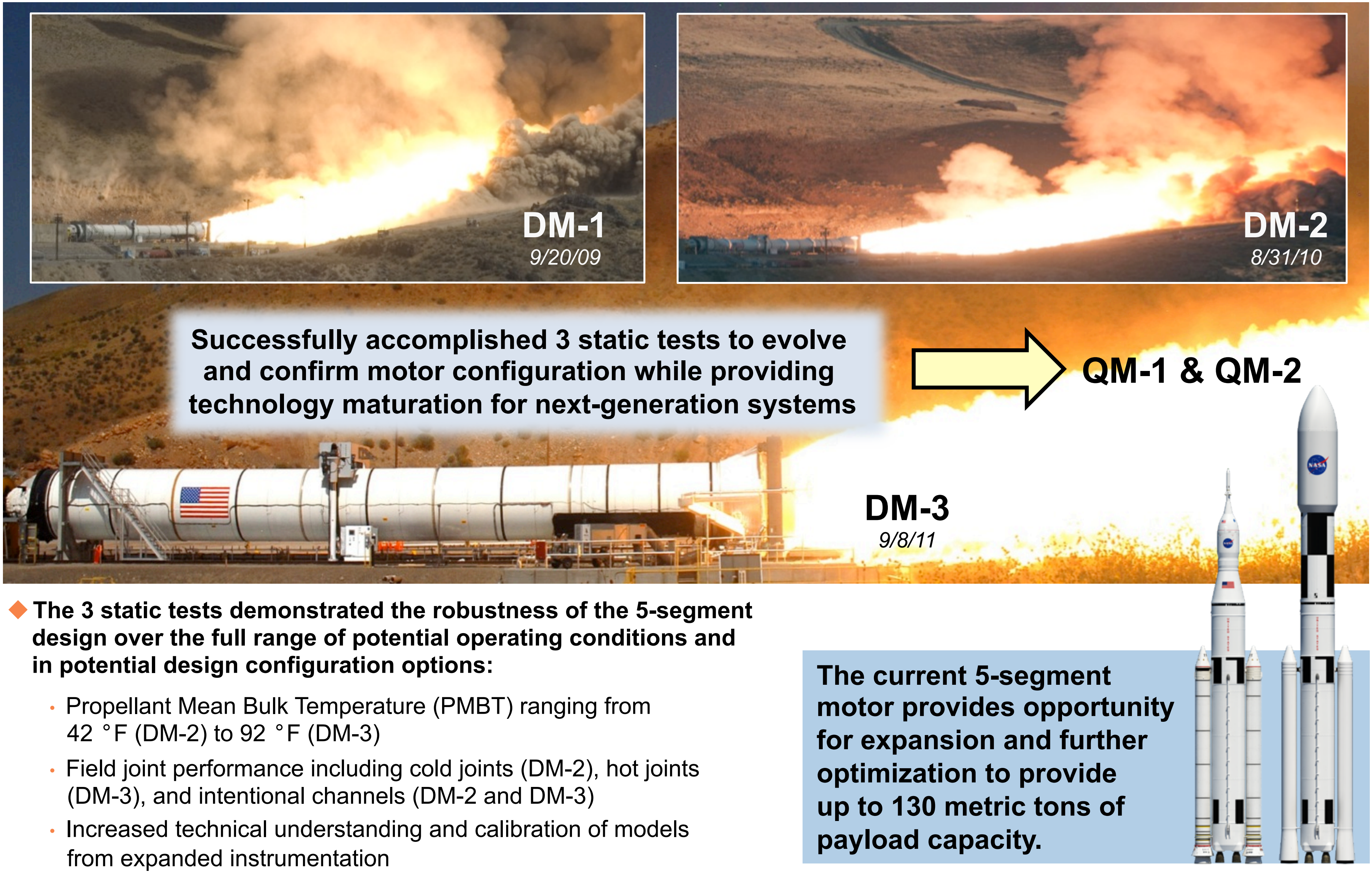
STS SRB Thermal Curtain



SLS Main Engine proximity to Booster Thermal Curtain results in increased loads (over SSME loads)

Technical Resolution Plans in Place to Address Challenges

Accomplishments: From Development to Qualification



Successfully accomplished 3 static tests to evolve and confirm motor configuration while providing technology maturation for next-generation systems

QM-1 & QM-2

- **The 3 static tests demonstrated the robustness of the 5-segment design over the full range of potential operating conditions and in potential design configuration options:**
  - Propellant Mean Bulk Temperature (PMBT) ranging from 42 °F (DM-2) to 92 °F (DM-3)
  - Field joint performance including cold joints (DM-2), hot joints (DM-3), and intentional channels (DM-2 and DM-3)
  - Increased technical understanding and calibration of models from expanded instrumentation

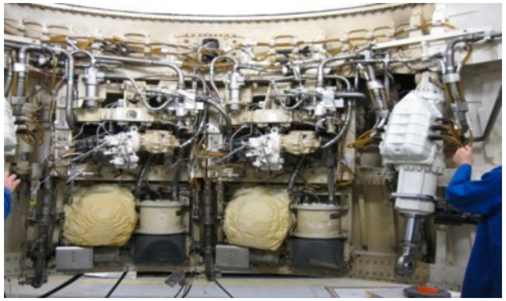
The current 5-segment motor provides opportunity for expansion and further optimization to provide up to 130 metric tons of payload capacity.

Accomplishments: From Development to Qualification (Continued)

- Avionics system development and maturation support for SLS Vehicle simulation tests and full scale static tests (QM-1 & -2)

Subsystem level testing
Completed Sep 2011

Flight Controls Test 1
Completed Mar 2012



Flight Controls Test 2
Completed Feb 2013

- SLS Booster Element successfully completed the Preliminary Design Review (PDR) Board 2 April 2013
  - Integrated Booster development on target for CDR maturity

SLS Booster Element is postured for a successful CDR and the booster design is on track to support a 2017 SLS first flight.

Interim Cryogenic Propulsion System (ICPS) Challenges and Solutions

René Ortega
Spacecraft and Payload Integration Office (SPIO) Chief Engineer
NASA Marshall Space Flight Center

July 15, 2013

Space Launch System

Agenda

- Opening Remarks
- RS-25 Engine
- Core Stage
- Booster
- **Interim Cryogenic Propulsion System**

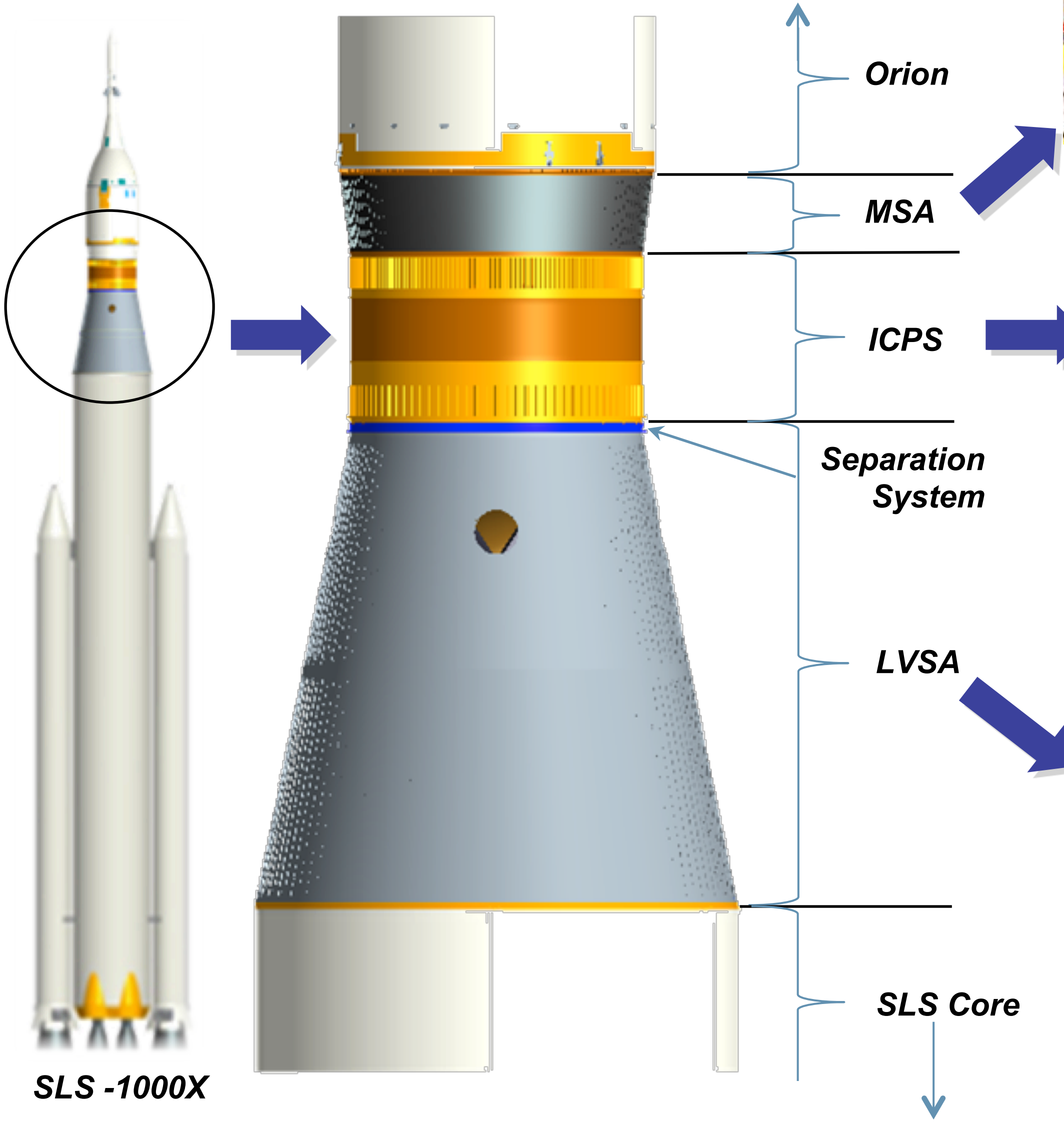
- Challenge: SLS vehicle design lateral loads imparted at liftoff and ascent mission phases

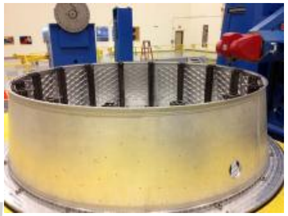
  Mitigations
  - For liftoff, incorporate T-zero stabilizer liftoff restraint and release, and additional system damping.
  - For ascent, incorporate additional RL 10B-2 system damping and vehicle test derived aero-buffeting factors.

- Challenge: Implementation of NASA Technical Specifications and Standards could impact the configuration and construction of the ICPS departing from configuration/ construction which has successfully flown over 20 flight.

  Mitigations
  - The SLS program tasked a team of experts to assess the risk associated with the use of the existing ULA design and construction methods for ICPS.
  - The team of experts will make recommendations to the SLS/Program on what deviations/waivers and/or mitigations are to be use.

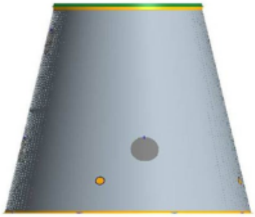
SLS Integrated Spacecraft and Payload Element (ISPE) Configuration (EM1)





MSA

ICPS



LVSA

ISPE

- ISPE for SLS-1000X is comprised of the Multi-Purpose Crew Vehicle (MPCV) Stage Adapter (MSA), Interim Cryogenic Propulsion Stage (ICPS), Separation System, and the Launch Vehicle Stage Adapter (LVSA)
- Managed by the Spacecraft and Payload Integration Office (SPIO) at NASA/MSFC, AL

MSA

- Manufactured by NASA Engineering/ MSFC, AL
- Connects ICPS to Orion adapter

ICPS

- Designed by Boeing/United Launch Alliance (ULA); ULA manufactured in Decatur, AL
- Modified 2016 production version of Delta Cryogenic Second Stage (DCSS) with RL10B-2 Engine
- Provides Perigee Raise and Trans-Lunar Injection and Disposal for EM1 & EM2

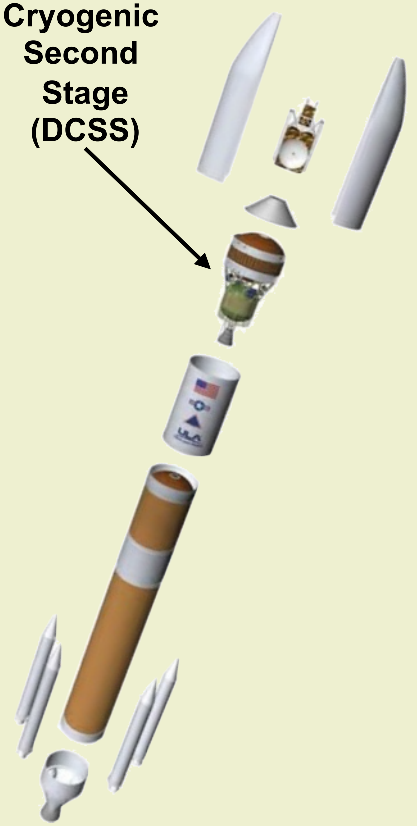
Separation System

- Manufactured by Chemring Energetic Devices/ULA
- Releases Orion/ICPS from SLS

LVSA

- Manufacturer TBD
- Connects ICPS to SLS and houses the separation system
- Preliminary design completed by NASA Engineering/MSFC, AL

Challenges Associated with Adapting Existing Delta IV Stage (DCSS) to the SLS ICPS

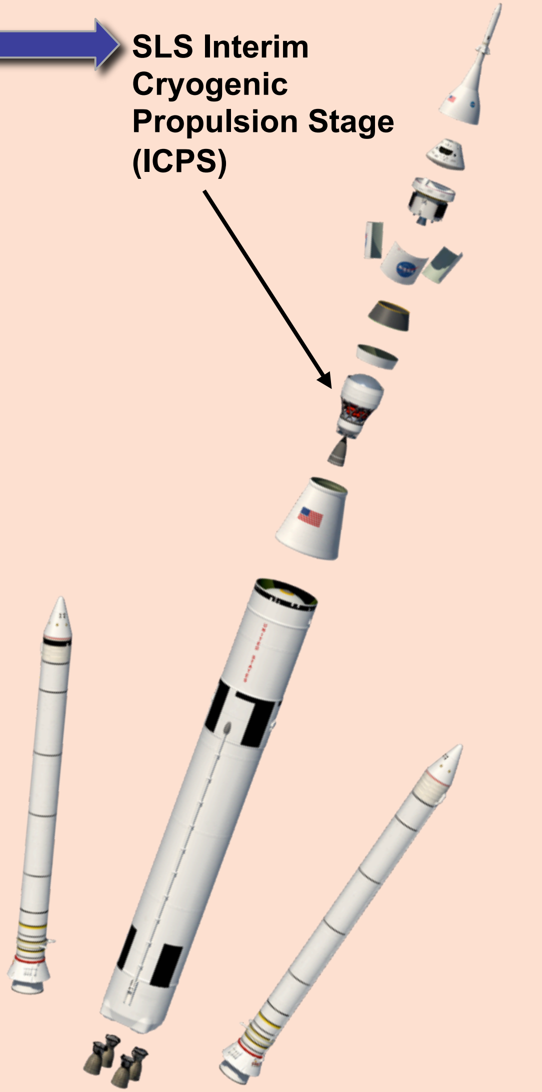


Delta IV Cryogenic Second Stage (DCSS)

Delta IV

DCSS to ICPS Considerations

- Payload mass (Orion)
- Vehicle physical fit and orientation
- Vehicle design loads
- Performance requirements
- Acoustic Environments
- Thermal Environments
- Range Safety communication frequency
- State vector correction
- Vehicle Integration Ground Operations
- Launch Pad Operations
- Ground Systems Support
- Mission Operations Flow
- In-Space Guidance Commands
- Interface Requirements & Definition
- Human rating
- Safety Hazards Management
- Reliability Requirements
- NASA vs. Contractor Standards
- Protection of Intellectual Property
- Incorporation and reliance of ongoing DCSS Avionics updates



SLS Interim Cryogenic Propulsion Stage (ICPS)

SLS-1000X

Major On-going DCSS to ICPS Challenges

- **SLS vehicle design loads that meet the ICPS RL10B-2 Electro-mechanical actuator (EMA) and engine qualification limits**
  - Design iterations usually include loads reduction and hardware capability iterations. For ICPS, being mostly heritage hardware, capability design iterations are limited.

Challenge: SLS vehicle design lateral loads imparted at liftoff and ascent mission phases are challenging

- Liftoff lateral loads primarily driven by North/South winds
- Ascent lateral loads primarily driven by aero-buffeting

Mitigations for Design Cycle Iteration

- For the liftoff event, the SLS vehicle incorporated a T-zero stabilizer (liftoff restraint and release), and additional Boeing/ULA ICPS recommended system damping into the vehicle loads model.
  - Additional liftoff wind limitations may be considered in further iteration
- For the ascent event, the SLS vehicle incorporated the additional RL 10B-2 system damping and vehicle test derived aero-buffeting factors into the vehicle loads model
  - An SLS aero-buffets team continues to study potential for vehicle loads reductions
    - Potential additional ICPS mitigation include exploring additional damping from active electro-mechanical actuators (EMAs) and other more complicated options

In a typical conservatively-derived design cycle, loads decrease and capability improves as the design matures. The challenge with using heritage hardware is that the capability is mostly fixed.

Major On-going DCSS to ICPS Challenges (Continued)

- **Implementation of NASA Technical Specifications and Standards for ICPS may result in costly redesigns for ICPS.**
  - The ICPS is a modification to the existing DCSS which was developed under United Launch Alliance (ULA) technical specifications and standards for commercial and military applications.
    - Intent was to implement modifications to a 2016 version of DCSS following contractor specifications.

Challenge: Implementation of NASA Technical Specifications and Standards could impact the configuration and construction of the ICPS departing from the basic DCSS configuration/construction which has successfully flown in Delta IV greater than 20 flights.

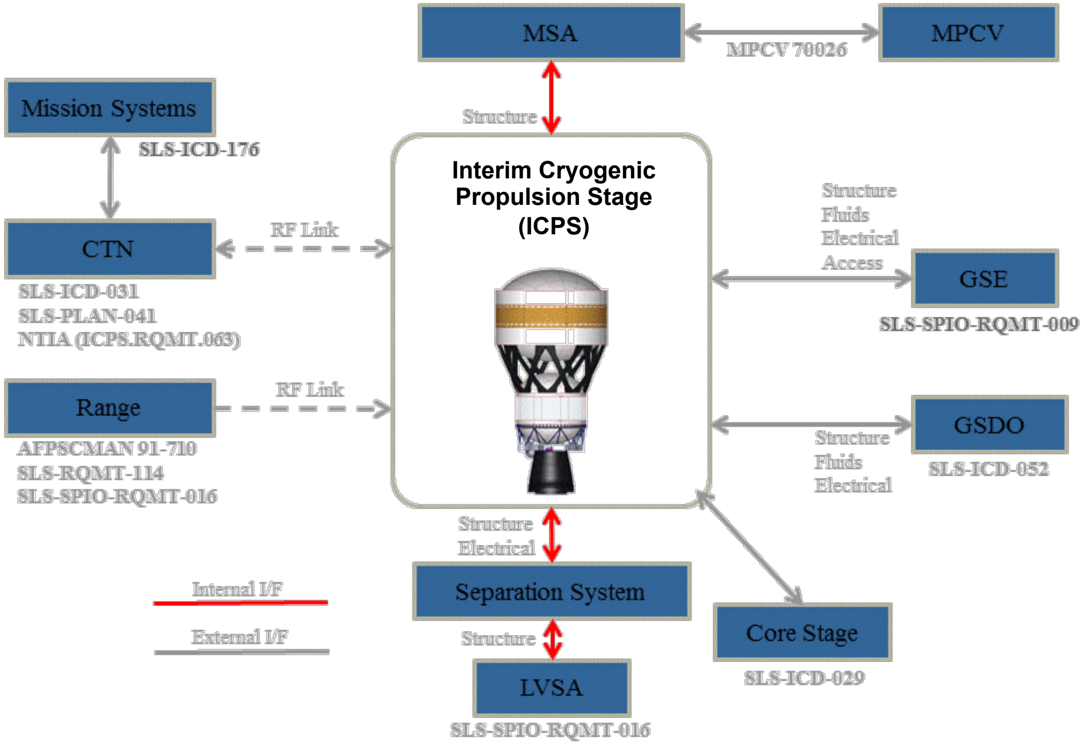
Mitigations

- The SLS program tasked a team of experts to review the related ULA and NASA Technical Specifications and Standards to assess the risk associated with the use of the existing ULA design and construction methods for ICPS.
- The team of experts will make recommendations to the SLS/Program on what deviations/ waivers and/or mitigations are to be used for the ICPS design and construction standards.

Implementing NASA specifications while buying off-the-shelve type manufactured hardware results in a challenging specifications process

Future DCSS to ICPS Challenge

ICPS Interface Context Diagram



MSA

MPCV 70026

MPCV

Structure

Mission Systems

SLS-ICD-176

Interim Cryogenic Propulsion Stage (ICPS)

CTN

RF Link

SLS-ICD-031
SLS-PLAN-041
NTIA (ICPS.RQMT.063)

Structure
Fluids
Electrical
Access

GSE

SLS-SPIO-RQMT-009

Range

RF Link

AFPSCMAN 91-710
SLS-RQMT-114
SLS-SPIO-RQMT-016

GSDO

Structure
Fluids
Electrical

SLS-ICD-052

Structure
Electrical

Internal I/F

External I/F

Separation System

Structure

LVSA

SLS-SPIO-RQMT-016

Core Stage

SLS-ICD-029

- **New and Existing ICPS Interface requirements mapping to the various SLS vehicle interface controlling requirements will require close detailed scrutiny as the design matures**
  - Effort may be workforce intensive
  - Involve various interface elements including SLS, Orion, Ground, SPIO, and Range
  - Effort will require a detailed verification process

Large number of interfaces may result in a challenging validation and verification process.

Accomplishments

- **Recent ISPE accomplishments include:**
  - Conducted a feasibility study indicating that ICPS has the capability to conduct the SLS mission.
  - ISPE Preliminary Design Review completed in June 2013.
  - Currently manufacturing flight MPCV Stage Adapter for Delta IV flight of MPCV in late 2014.
  - Incorporated into the ICPS design an extension of the hydrogen tank for added stage performance.

SPIO has an experienced committed team working to resolve all challenges.

America’s Rocket

www.nasa.gov/sls