SPACE LAUNCH SYSTEM

5...4...3...2...1...

SLS Technology Insertion Approach

Fred Bickley, PhD
Space Launch System Program

www.nasa.gov/sls
THE WORLD’S MOST POWERFUL ROCKET

Orion

Interim Cryogenic Propulsion Stage

Block I
70 metric tons

Five-Segment Solid Rocket Boosters

Upper Stage

Core Stage

4 RS-25 Engines

Block II
130 metric tons

Liquid or Solid Advanced Boosters

5, 8.4 or 10 Meter Payload Fairings

5, 8.4 or 10 Meter Payload Fairings
Technology Transition

Valley of Death

Level of Development

Operational Phase

Product Development

Advanced Development

Technology Development

Ideas Research

Advanced Development

Product Development

Level of Development

TRL
**SLS Approach to Block Upgrades**

*Improvements in Performance, Safety, Reliability, Cost, and Operations*

Notional Schedules

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**Block 1B**

- **Requirements**
- **Advanced Development**
- **Design/Development**
- **Mission**

**Block 2**

- **Requirements**
- **Advanced Development**
- **Design/Development**
- **Mission**

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* NASA, Office of Chief Technologist (TRL 1-6)
### Current Advanced Development Tasks

#### In-house Tasks:

- Cryogenic Mat’l & Process Development–Mitigate Obsolescence
- Hexavalent Chromium Free Primer for Cryo
- MPS Low Profile Diffuser
- Solid State Ultracapacitor to Replace Batteries Lattice
- Boltzmann Modeling Zero-G Propellants
- Hot fire Test LOX/H2 Additively Manu’f Injector Affordable for EUS
- Testing of Additively Manu’f Turbomachinery
- Additive Manufacturing Infrared Inspection
- Computed Tomography Sensitivity & Verification of Engine Components
- Adv. Manuf. Of Lightweight C-C Nozzle Ext. for Upper Stage
- Performance Improvement of Friction Stir Welds by Better Surface Finish
- Composite Dry Structure Cost Improvement Approach
- Q2 Inconel 625 Mat’l Properties Development
- Q4 titanium 6–4 Mat’l Properties Development
- Pyroshock Characterization of Composite Materials (NESC funded)
- Booster Interference Loads (NESC funded)
- Advanced Booster comp. Case/PBI NBR Insulation Dev (NESC funded)
- Advanced Booster Combustion Stability (NESC funded)

#### Academia Tasks:

- Auburn University: High Electrical Density Device Survey for Aerospace Applications
- Louisiana State University: Improved Friction Stir Welds Using On-Line Sensing of Weld Quality
- Massachusetts Institute of Technology: Modeling Approach for Rotating Cavitation Instabilities in Rocket Engine Turbopumps
- Mississippi State University: Algorithmic Enhancement for High Resolution Hybrid RANS-LES and Large-Scale Multicore Architectures
- University of Florida: Development of Subcritical Atomization Models for Liquid Rocket Injectors and Two-Phase Flow Heat Transfer
- University of Maryland: Validation of Supersonic Film Cooling Numerical Simulations Using Detailed Measurement and Novel Diagnostics
- Flame Stabilization and Combustion Instabilities University of Utah: Acoustic Emission Based Health Monitoring of Structures
- Pennsylvania State University: Characterization of Aluminum/Alumina/Carbon Interactions under Simulated Rocket Motor Conditions

#### Awarded Industry Tasks:

- Aerojet: AUSEP Engine Study
- Exquadrum, Inc: AUSEP/DESLA Concept Development
- Moog: AUSE High Press LOX Flow Control Valve Manufacturing Study
- Northrup Grumman: System Requirements and Affordability Assessment for an AUSE
- Pratt & Whitney Rocketdyne: Requirements, Logistics, and System Assessment of an AUSE
- ULA: Integrated Vehicle Fluids (IVF) Testing

#### Advanced Booster Engineering Demonstration and Risk Reduction Tasks (ABEDRR):

- Dynetics & Aerojet: Modernization of the F-1B Engines, Combustion Stability, and Cryotank Manufacturing
- ATK: Demonstration of a FWC for High-Energy Propellant SRB
- Northrop Grumman: Demonstration of a Common Bulkhead LOX/RP Composite Cryogenic Tank

Details of individual tasks can be found at [www.ntrs.nasa.gov](http://www.ntrs.nasa.gov) (search for NASA/TM-2015-218201) in the SLS SPIE Advanced Development FY14 Annual Report.
SLS Advanced Development Group Technology Focus Areas

◆ SLS Industry Task Focus Areas
  • Exploration Upper Stage (EUS)
    - Light weight structures and materials, including composites
    - Advanced LOX/LH2 engine
    - Cryogenic storage for long duration missions
    - Advanced/Additive Manufacturing (Selective Laser Melting)
  • Universal Stage Adapter
    - Light weight structures and materials, including composites
    - Design

◆ SLS In-House and Academic Task Focus Areas
  • Propulsion
  • Stages, including upper stages
  • Advanced boosters
  • Shrouds
  • Operations
  • Payload accommodations
  • Analytical modeling
  • Advanced manufacturing
  • Materials development
Outer Loop Evolvability Update

Angie Jackman/XP50
Game-changing Power For Exploration

- Human Missions to Mars
- Mars Sample Return
- Europa Exploration
- Ultra-Large Space Telescopes
- Interstellar Probe
- Asteroid Redirect Mission
- Space Stations
- Enceladus Geyser Sample Return

NASA's Space Launch System
SLS Evolution Overview

- Block 1
  - Core Stage
  - Interim Cryogenic Propulsion Stage
  - Orion
  - Launch Vehicle Stage Adapter
  - Solid Rocket Boosters
  - RS-25 Engines

- Block 1B Crew
  - Core Stage
  - Exploration Upper Stage
  - Interstage
  - Solid Rocket Boosters

- Block 1B Cargo
  - Core Stage
  - Exploration Upper Stage
  - Interstage
  - Solid Rocket Boosters

- Block 2 Cargo
  - Core Stage
  - Exploration Upper Stage
  - Interstage
  - Advance Boosters
  - Cargo Fairings
Upcoming Industry Forecast

Bryan Barley/XP50
Industry
- Awards: Multiple
- Period of Performance: 1 year base (up to 18 months base period allowed), one 1 year option

Type Solicitation:
- NASA Research Announcement (NRA)
- Designed for contracts or cooperative agreements

Type of Contract: Firm Fixed Price (FFP)

Anticipated Solicitation Announcement: FY15

Anticipated ATP: FY16
SLS Industry Task Focus Areas

- Exploration Upper Stage (EUS)
  - Light weight structures and materials, including composites
  - Advanced LOX/LH2 engine
  - Cryogenic storage for long duration missions
  - Advanced/Additive Manufacturing (Selective Laser Melting)

- Universal Stage Adapter
  - Light weight structures and materials, including composites
  - Design

Focus on these calls is based on the needs for Block 1B and the reasonable projection of readiness to implement at that time
ADG Examples (Industry)

IVF (ULA)

Augment Expander Cycle Engine Concept (Aerojet)

SLM Inconel 718 LOX Valve (Moog)

www.nasa.gov/sls

Turbopump Assy Concept (Northrup Grumman)
ADG Examples (Industry)

Composite Tank (Northrup Grumman)
Previous Significant Accomplishments - Industry

**AUSEP**

The Air Force’s Advanced/Affordable Upper Stage Engine program (AUSEP) is an initiative to develop an affordable upper stage engine concept that will be a replacement for the RL10 engine. The AUSEP engine has the requirement for 30,000 lb of thrust with the performance of the RL10B-2 that can be packaged in the envelope of an RL10A-4 to support USAF evolved expendable launch vehicle (EELV) missions using existing Atlas and Delta launch vehicles.

- **Aerojet achievements:**
  - Developed the major subsystems requirements associated verification requirements & documents.
  - Developed power balance for 30K-lb operation and for an additional throttleable 5K lbf thrust.
  - Developed DDT&E cost and schedule estimate.
  - Developed a flight engine production and delivery schedule.
  - Delivered a final flight engine architectural layout with a nozzle profile that aligned with AUSEP requirements.

- **Pratt & Whitney Rocketdyne (PWR) achievements:**
  - Developed power balance models for several candidate upper stage engine architectures.
  - Developed a high-fidelity utility function balancing the main trade factors based upon customer inputs.
  - Developed recurring & nonrecurring cost estimates for three candidate RL-10 replacement engine cycle configurations.
  - Completed validation plan and established program schedules for potential development.
  - Provided a technical report focused on three engine configuration concepts to replace the RL-10.

- **Exquadrum achievements:**
  - Performed functional decomposition of AUSEP system requirements and trade space definition document.
  - Conducted turbomachinery trades and analyses.
  - Developed an integrated an aerospike engine configuration into a Centaur upper stage (geometric fit).
  - Developed recurring & nonrecurring cost estimates for the candidate RL-10 replacement engine.
  - Provided a technical report focused on the aerospike engine configuration concept to replace the RL-10.
Previous Significant Accomplishments - Industry

**AUSEP (cont’d)**
- Moog accomplishments:
  - Completed the design, development, fabrication, and test of a high-pressure cryogenic LOX control valve.
  - Conducted an assessment of the Inconel 718 DMLS AM valve, including measuring seal friction and leakage, measuring flow rates, and oxygen compatibility.
  - Provided a Technical Report regarding the development and test findings.

- Northrup Grumman Aerospace System (NGAS) achievements:
  - Performed functional decomposition of AUSEP system requirements and trade space definition document.
  - Completed turbomachinery trades and analyses.
  - Delivered recurring and nonrecurring cost and schedule estimates for the design, development, test, and evaluation.
  - Finalize and deliver the recurring and nonrecurring cost and schedule estimates for the design, development, test, and evaluation of the advanced upper stage engine.
  - Produced a final Technical Report focused on NGAS closed expander Engine Conceptual Design.

- United Launch Alliance achievements:
  - Developed and fabricated an internal combustion engine (ICE), cryogenic compressor, and a five heat exchanger complement.
  - Incorporated flight-worthy Krytox lubricants and coolants into the IVF ICE configuration.
  - Upgraded the IVF test facility to enable high-flow testing with cryogenic hydrogen and oxygen.
  - Developed and fabricated a first generation IVF controller.
  - Currently testing the Generation 1.5 integrated IVF system at Innovative Engineering Services (IES); tests include operation with liquid and gaseous hydrogen and oxygen.
  - Current Gen 1.5 IVF system is used to demonstrate the IVF’s system-level function.
ABEDRR Task

Northrup Grumman Aerospace System (NGAS) Advanced Booster achievements include the following:

- Successfully built out-of-autoclave test panels, fuel and oxidizer unitized tank halves.
- Designed and fabricated test fixture.
- Fabricated and outfitted the test stand with fixtures, including the substitute fuel (diesel) supply tank.
- Assessed and identified hazards associated with CTS testing.
- Completed the mating of the out-of-autoclave unitized composite tank halves and installation of tank fixtures.
- Preparing for testing in April 2015 (Madison, AL).
Upcoming Academic and In-House Forecast

Mindy Nettles/XP50
ADG Task Award Process

**Academia**
- Period of Performance: 1 year base, one 1 year option
- Contract Vehicle: Grant
- Anticipated Solicitation Announcement: CY15
- Anticipated ATP: CY16

*Teaming is possible on these activities. Over the last few years ATK and the University of Utah collaborated on an activity and MIT- Aerospace Corporation on another.*

**In-House**
- Period of Performance: 1 year base, 1 year option
- Contract Vehicle: N/A
- Anticipated Call for Proposals: FY15
- Anticipated ATP: FY16

*Teaming on these would involve an SAA with the performing organization.*

*Another potential way to augment both the in-house and academic tasks is through the Cooperative Agreements.*
SLS Advanced Development Group Technology Focus Areas

- SLS In-House and Academic Task Focus Areas
  - Propulsion
  - Operations
  - Analytical modeling
  - Light weight structures
  - Advanced/Additive Manufacturing
  - Materials Obsolescence
  - Energy Storage

*Focus on these calls is based on the needs for Block 1B and the reasonable projection of readiness to implement at that time*
ADG Examples (In-House)

- Hexavalent Chromate-Free Primer
- Additive Manufacturing 3-D Printer
- Ultra-Capacitor
- SLM Ti6-4 Turbopump Impeller
- LOX/H2 SLM Injector Testing
- Low-Profile Diffuser
Previous Significant Accomplishments (In-House)

◆ Solid State Ultracapacitor to Replace Batteries
  • A number of patents (6) and spin-off technologies have resulted from these efforts. Dr. Terry Rolin was honored with the “Lean Forward; Fail Smart” Agency level award for innovation in 2015.

◆ Performance Improvement of Friction Stir Welds by Better Surface Finish
  • Modification of existing tools to accelerate smoothing of weld and increasing fidelity of inspection. Reducing the number of false-positives

◆ Additive manufacturing
  • Developing fracture criteria for parts
  • Cooperatively with industry and other government agencies, developing protocol for testing and building a preliminary material property database

◆ Contractor interest/incorporation of the following tasks
  • Gore stretching
  • Manual TPS spray
  • Low Profile Diffuser
ADG Examples (Academic)

- **Injector Subcritical Atomization Simulation (U of FL)**
- **LPT for Primary Drops**
- **LPT + Evaporation for Secondary Drops**
- **Stochastic Model for Atomization**
- **Flamelet Solver for Turbulent Combustion**
- **Time Averaged**
- **Time Sliced**
- **Time Averaged**

- **Unsteady Burning in Coaxial Element (U of Michigan)**
- **J-2X Film-Cooled Nozzle Extension (U of MD)**
- **High Order Unstructured CFD (MS State U)**
Previous Significant Accomplishments (Academia)

◆ 5 projects building on the Loci family of codes for liquid propulsion
  • Super and sub sonic film cooling, reduce conservatism in design of nozzle extensions by increasing fidelity of nozzle flow environments
  • Modeling heat transfer of chilldown lines both in-space on for ground systems
  • Improving physics based modeling data for combustion instability
  • Next Generation Simulation Infrastructure for Large Scale Multicore Architectures

◆ Inducer designed and fabricated at MIT, tested in the Aerospace Corporation’s water flow test facility. Results from the test will provide a baseline for validation of the body force methodology

◆ Specialized testing capability at Auburn University provides additional characterization of ultracapacitor components
ADG Examples  (Academic)

- **12 contracted activities with academic institutions**
  - 11 grants
  - 1 contract
  - 1 cooperative agreement

- **Over 60 students involved**
  - 15 BS
  - 20 MS, 11 with degrees conferred relating directly to SLS funded project
  - 26 PhD, 16 with degrees conferred relating directly to SLS funded project

- **10 Post-Doctoral consultants**

The value of the academic activities goes beyond the deliverables from the projects. The number of students and professors participating in and benefitting from these grants provides an opportunity to influence not only the curriculum at major universities, but to infuse individuals into the workplace who are familiar with the needs and challenges of the SLS program.