
National Aeronautics and Space Administration
NASA
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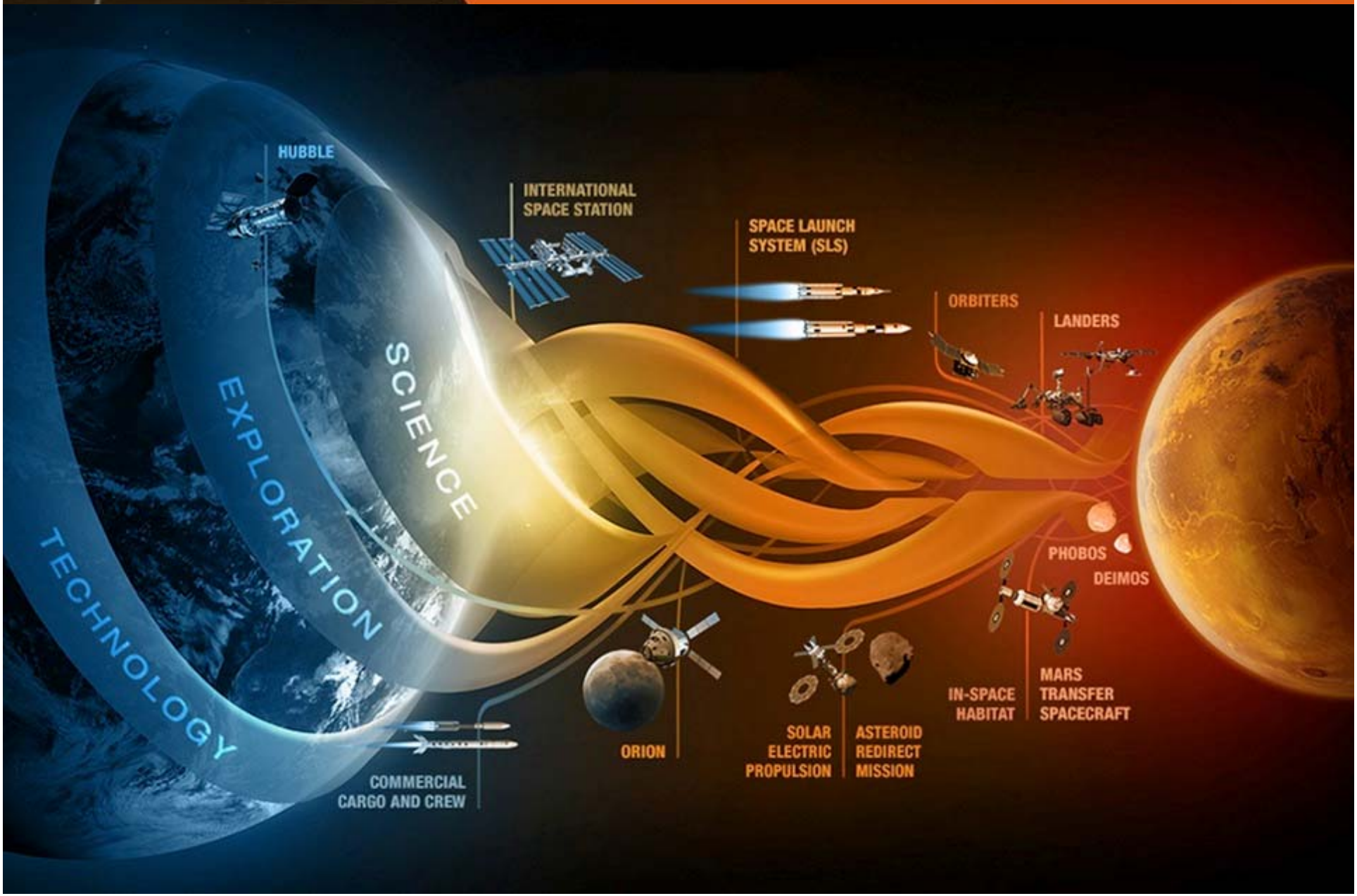
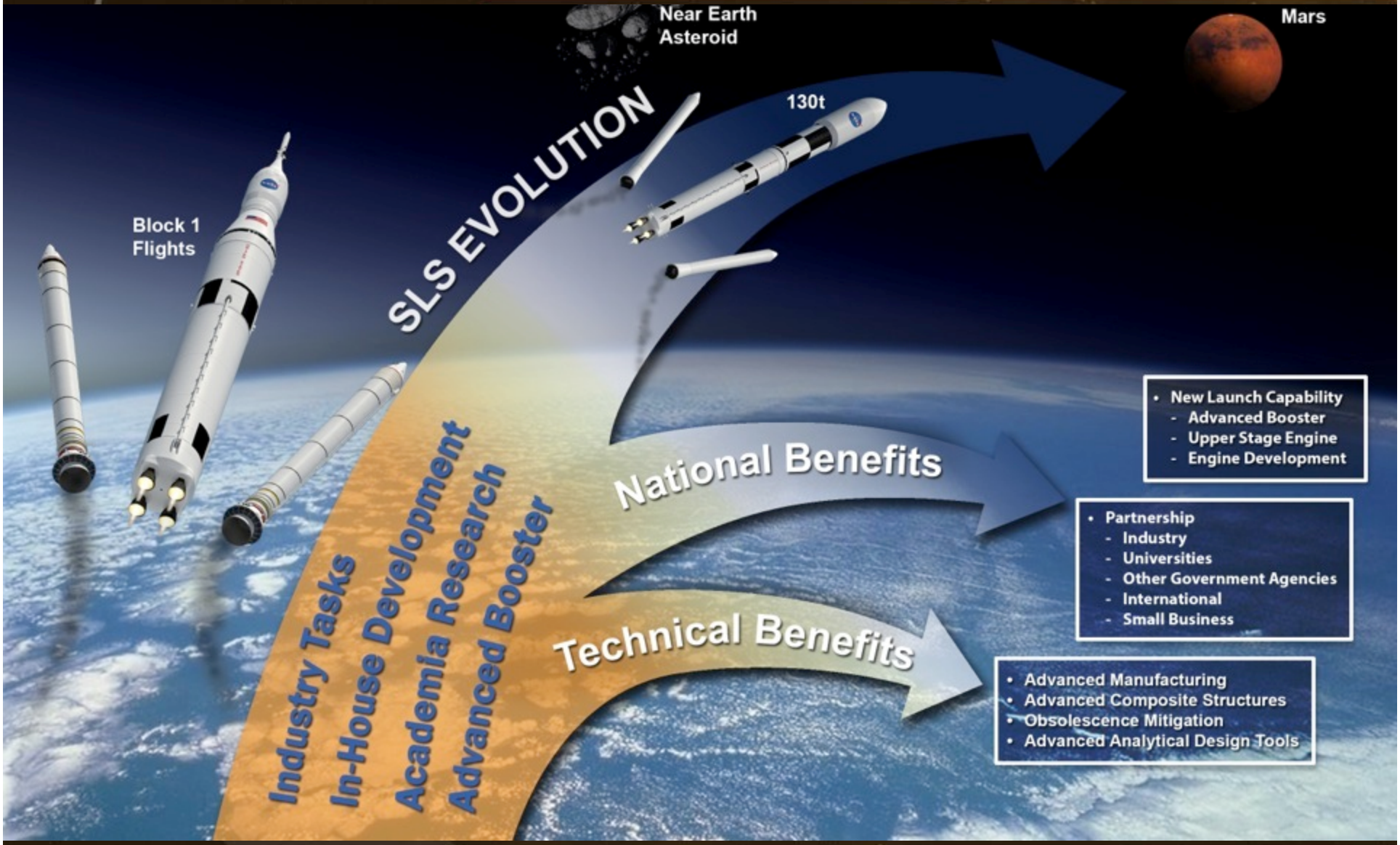
SPACE LAUNCH SYSTEM
SLS Technology Insertion Approach
Fred Bickley, PhD
Space Launch System Program
www.nasa.gov/sls
SLS
SPACE LAUNCH SYSTEM

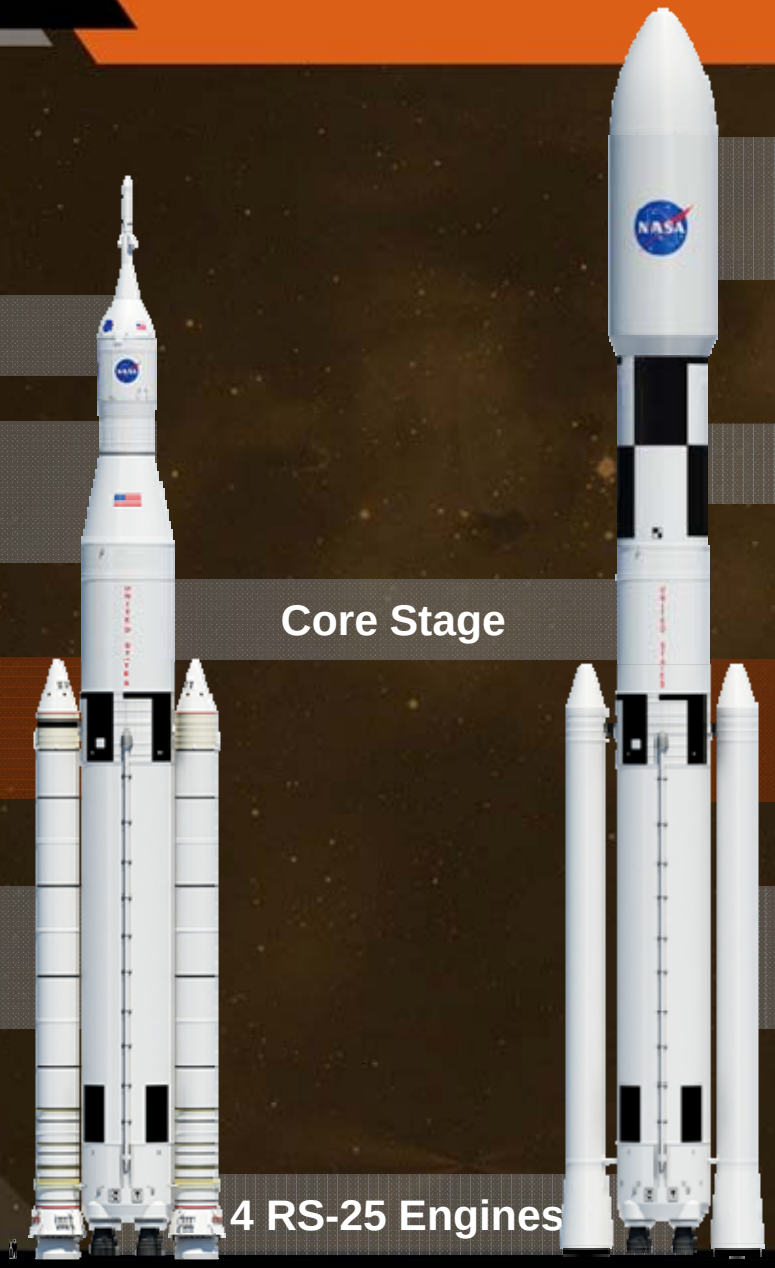
THE JOURNEY TO MARS



EVOLVING THE VEHICLE



THE WORLD'S MOST POWERFUL ROCKET



Orion

Interim Cryogenic Propulsion Stage

Block I
70 metric tons

Five-Segment Solid Rocket Boosters

5, 8.4 or 10 Meter Payload Fairings

Upper Stage

Core Stage

Block II
130 metric tons

Liquid or Solid Advanced Boosters

4 RS-25 Engines

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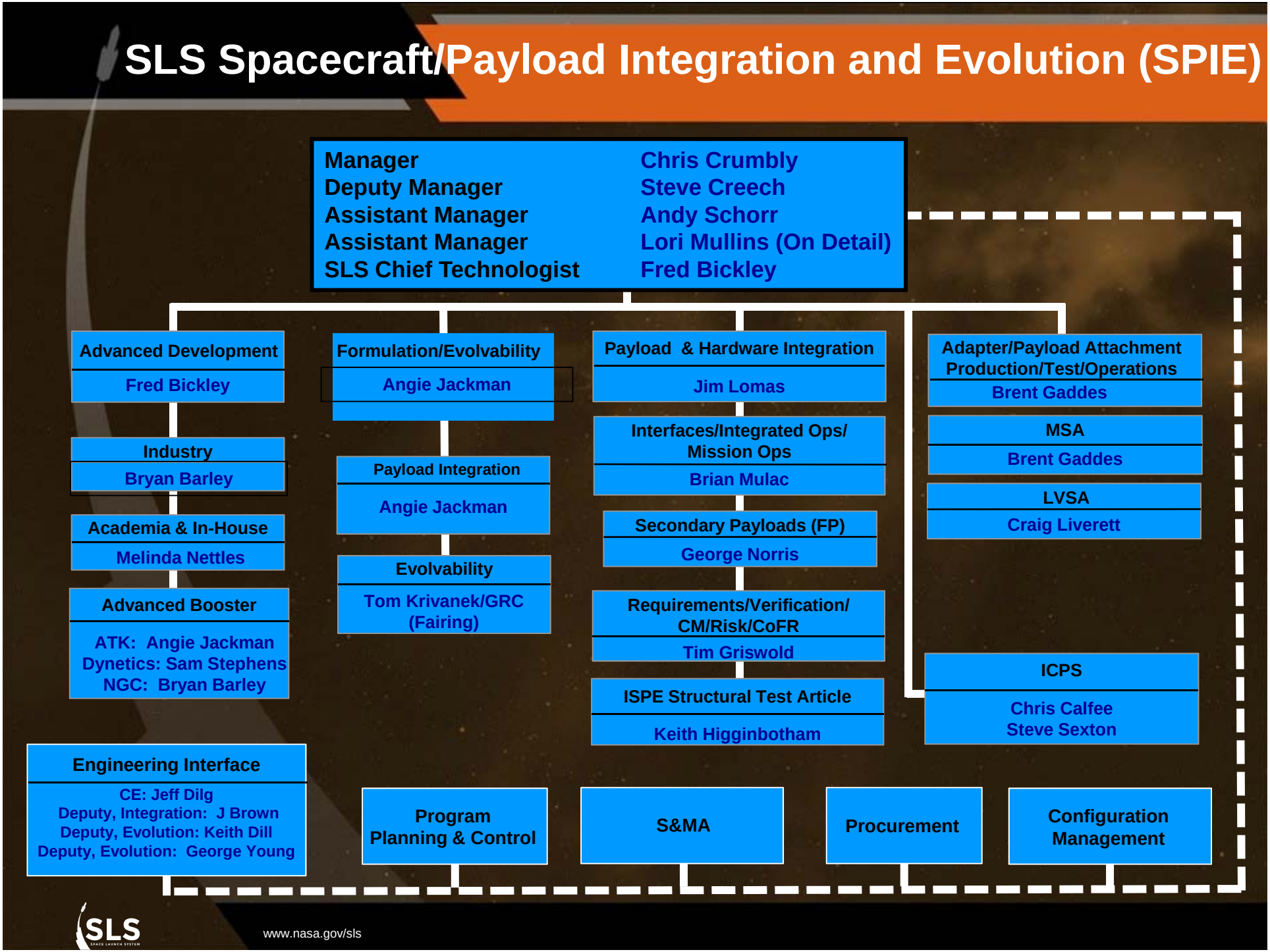
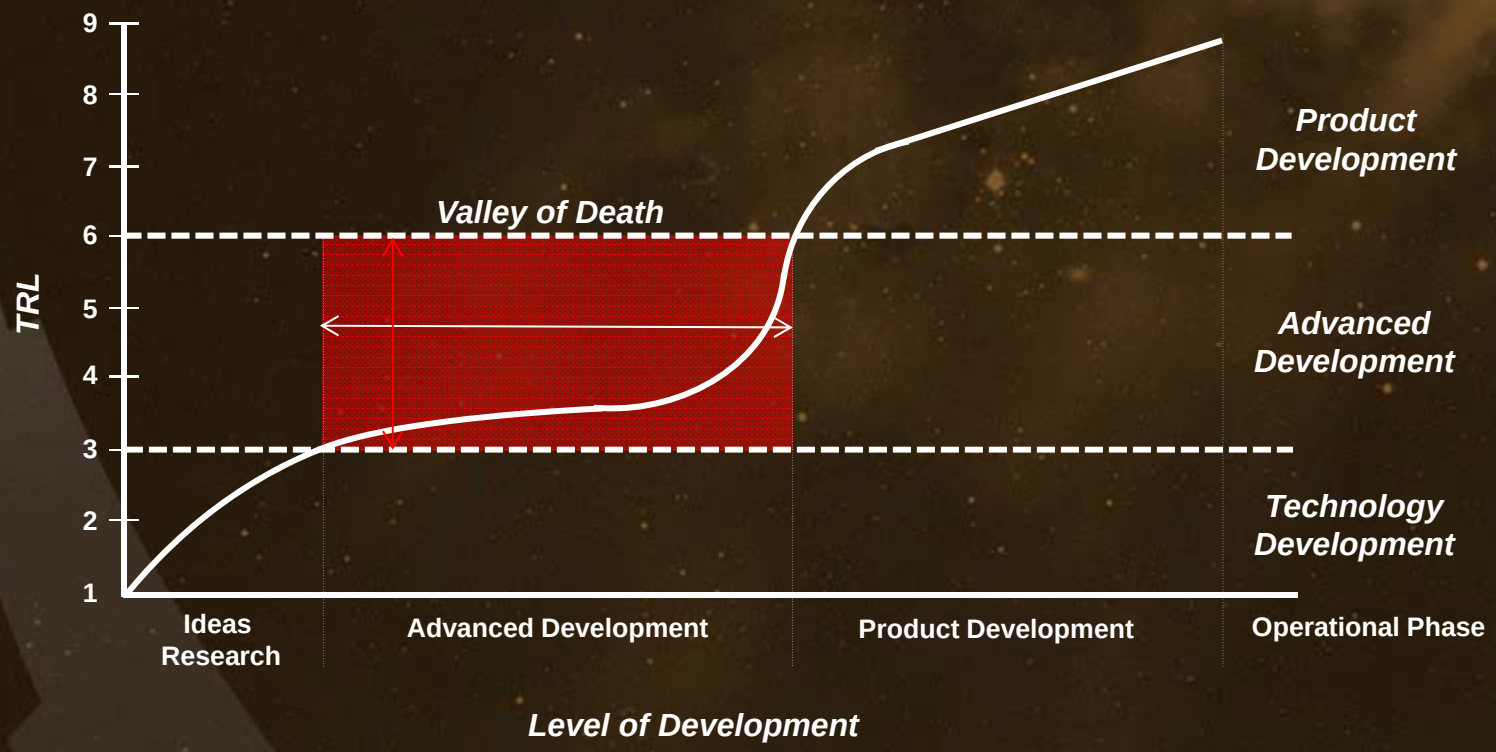
SLS Spacecraft/Payload Integration and Evolution (SPIE)



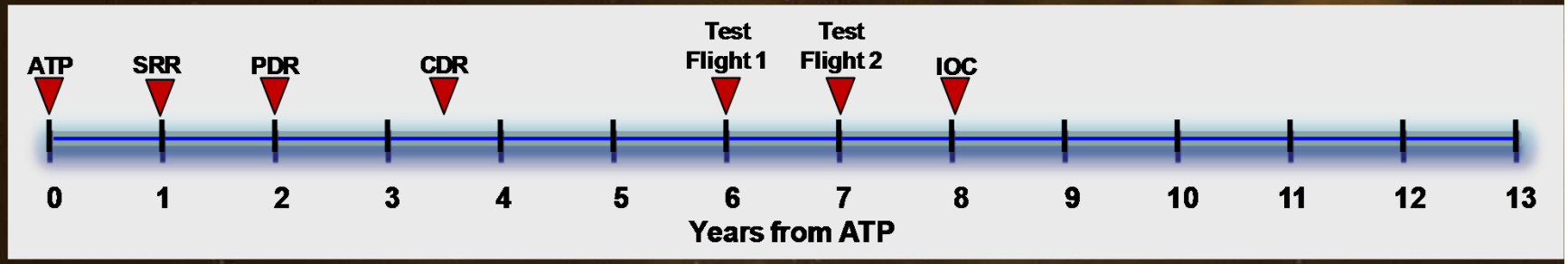
Technology Transition



SLS Approach to Block Upgrades

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

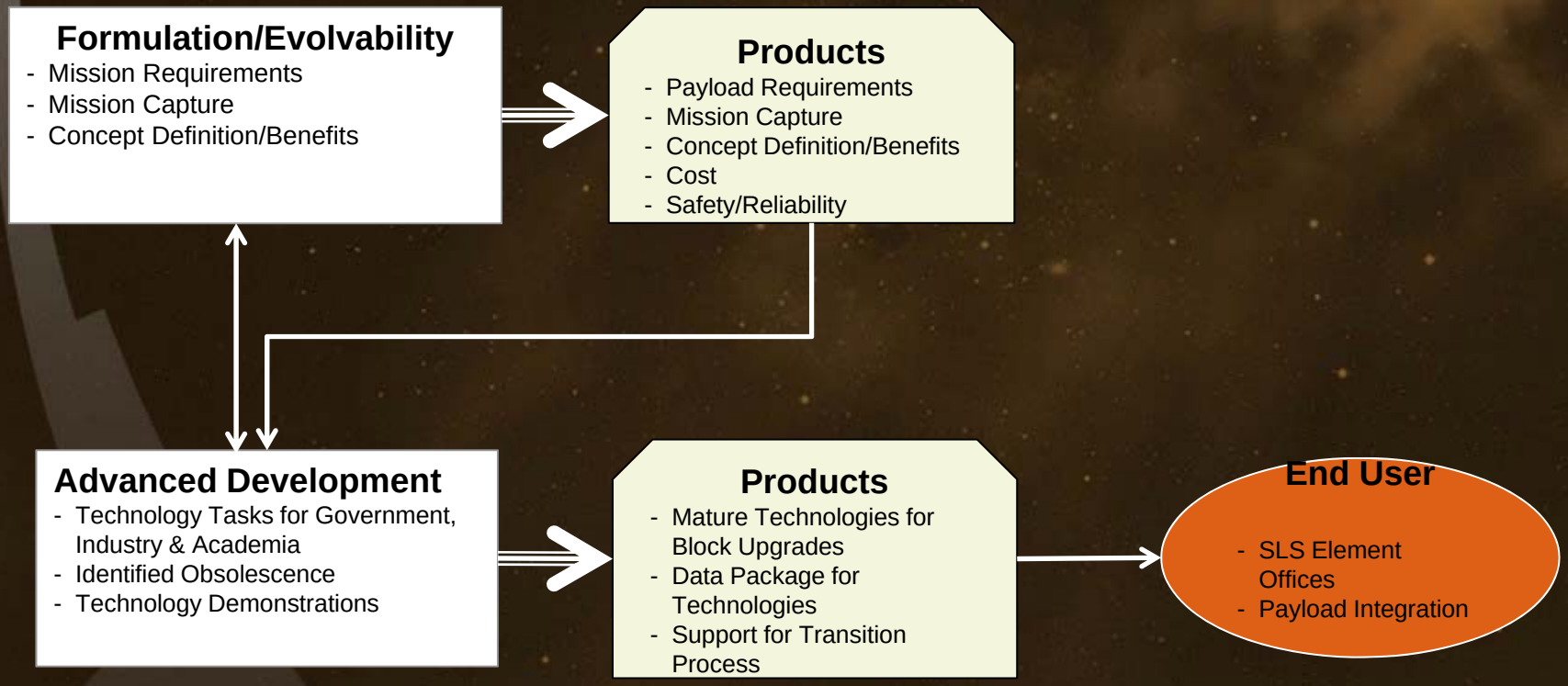
Notional Schedules



Block 1B Requirements	***Advanced Development***	***Block 1B Design/Development***	***Block 1B Mission***
Block 2 Requirements	***Technology Maturation**** / ***Advanced Development***	***Block 2 Design/Development***	***Block 2 Mission***

*** NASA, Office of Chief Technologist (TRL 1-6)**

Technology Needs



Current Advanced Development Tasks

In-house Tasks:

- Cryogenic Mat'l & Process Development–Mitigate Obsolescence
- Hexavalent Chromium Free Primer for Cryo
- MPS Low Profile Diffuser
- Solide 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
- Additive Manuf. Propellant Ducts, Manifolds & Bellows
- 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 Mar'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
- University of Michigan: Advanced LES and Laser Diagnostics to Model Transient Combustion-Dynamic Processes in Rocket Engines: Prediction of Flame Stabilization and Combustion Instabilities
- 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 (search for NASA/TM-2015-218201) in the SLS SPIE Advanced Development FY14 Annual Report.

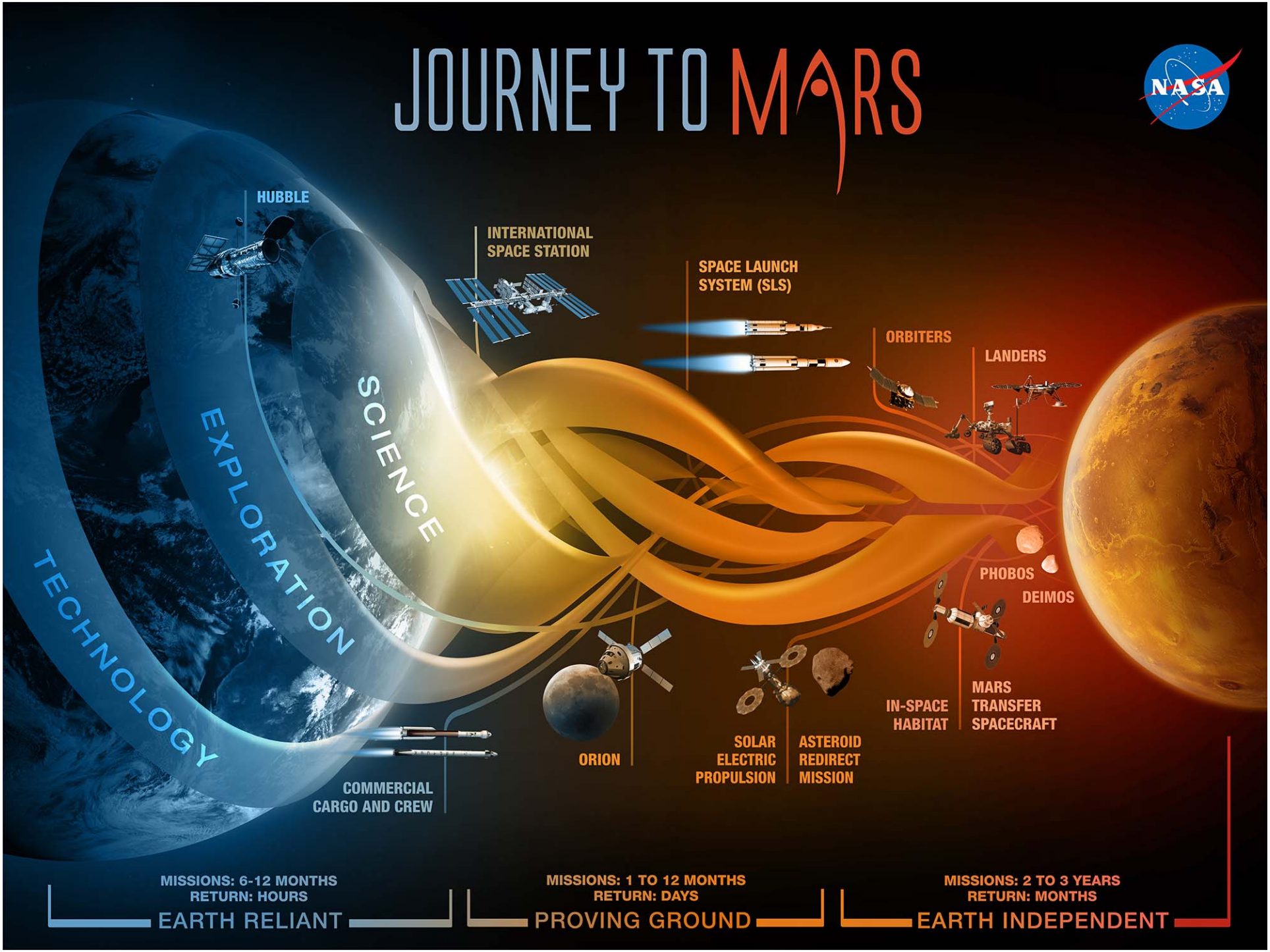
SLS Advanced Development Group Technology Focus Areas

- 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

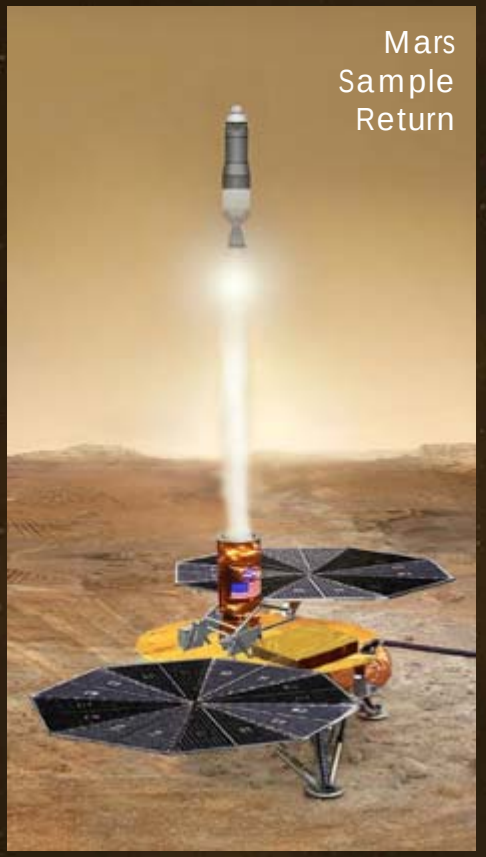
- SLS In-House and Academic Task Focus Areas
  - Propulsion
  - Stages, including upper stages
  - Advanced boosters
  - Shrouds
  - Operations
  - Payload accommodations
  - Analytical modeling
  - Advanced manufacturing
  - Materials development

Outer Loop Evolvability Update

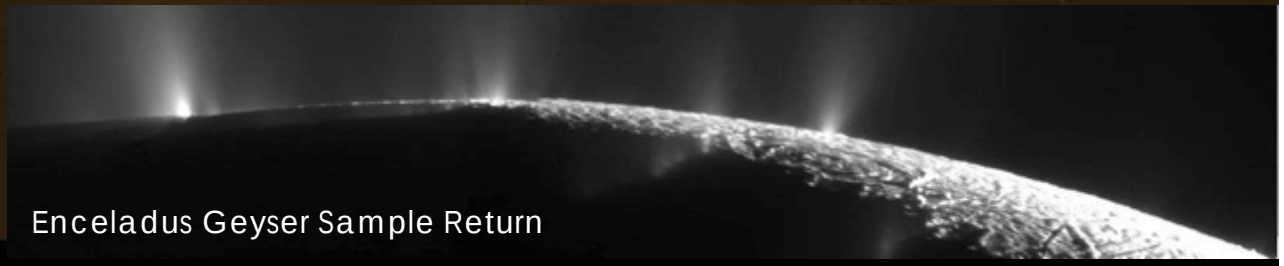
Angie Jackman/XP50


JOURNEY TO MARS
NASA
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
IN-SPACE HABITAT
MARS TRANSFER SPACECRAFT
ORION
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
COMMERCIAL CARGO AND CREW
MISSIONS: 6-12 MONTHS
RETURN: HOURS
EARTH RELIANT
MISSIONS: 1 TO 12 MONTHS
RETURN: DAYS
PROVING GROUND
MISSIONS: 2 TO 3 YEARS
RETURN: MONTHS
EARTH INDEPENDENT

Game-changing Power For Exploration



NASA's Space Launch System



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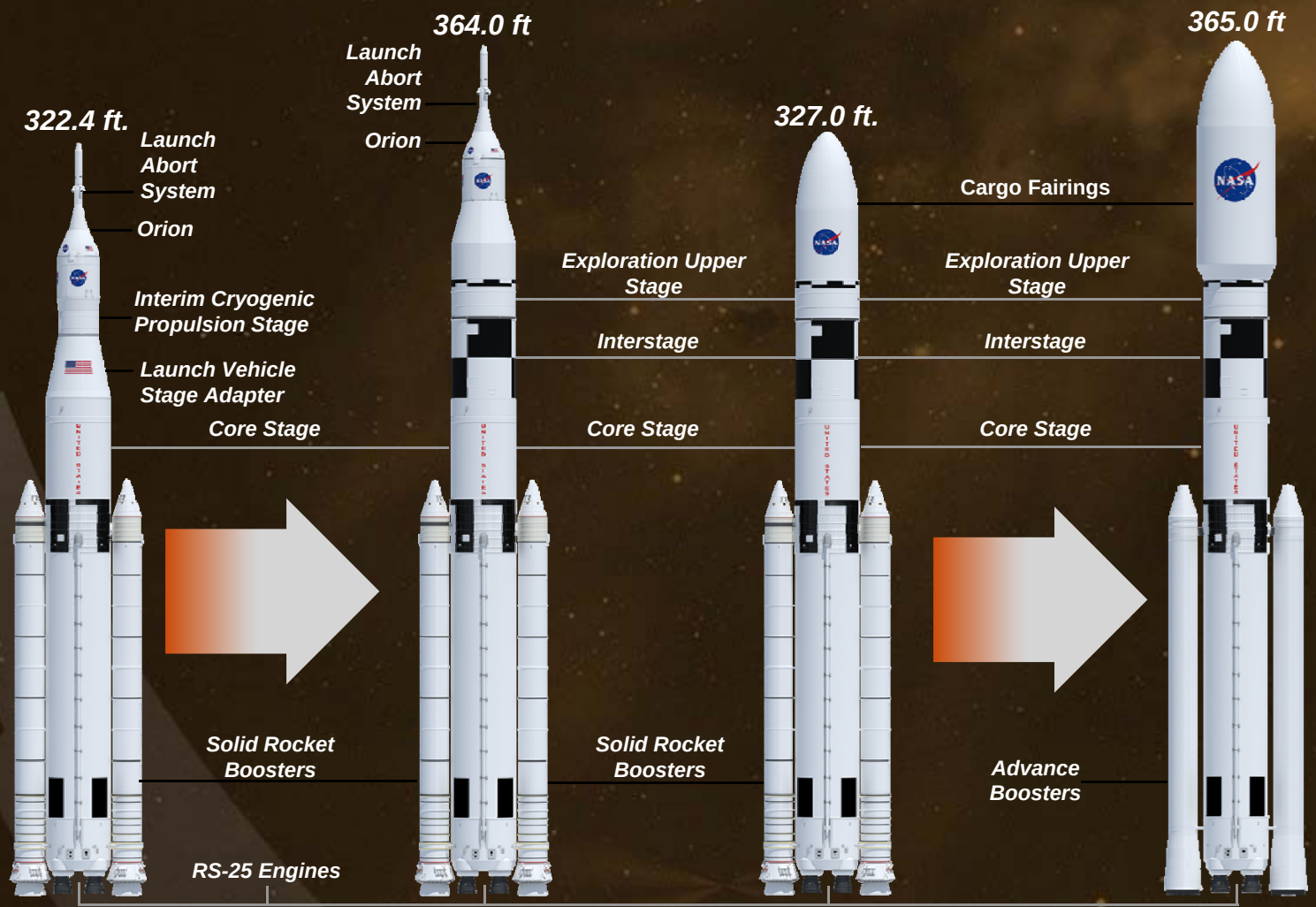
SLS Evolution Overview



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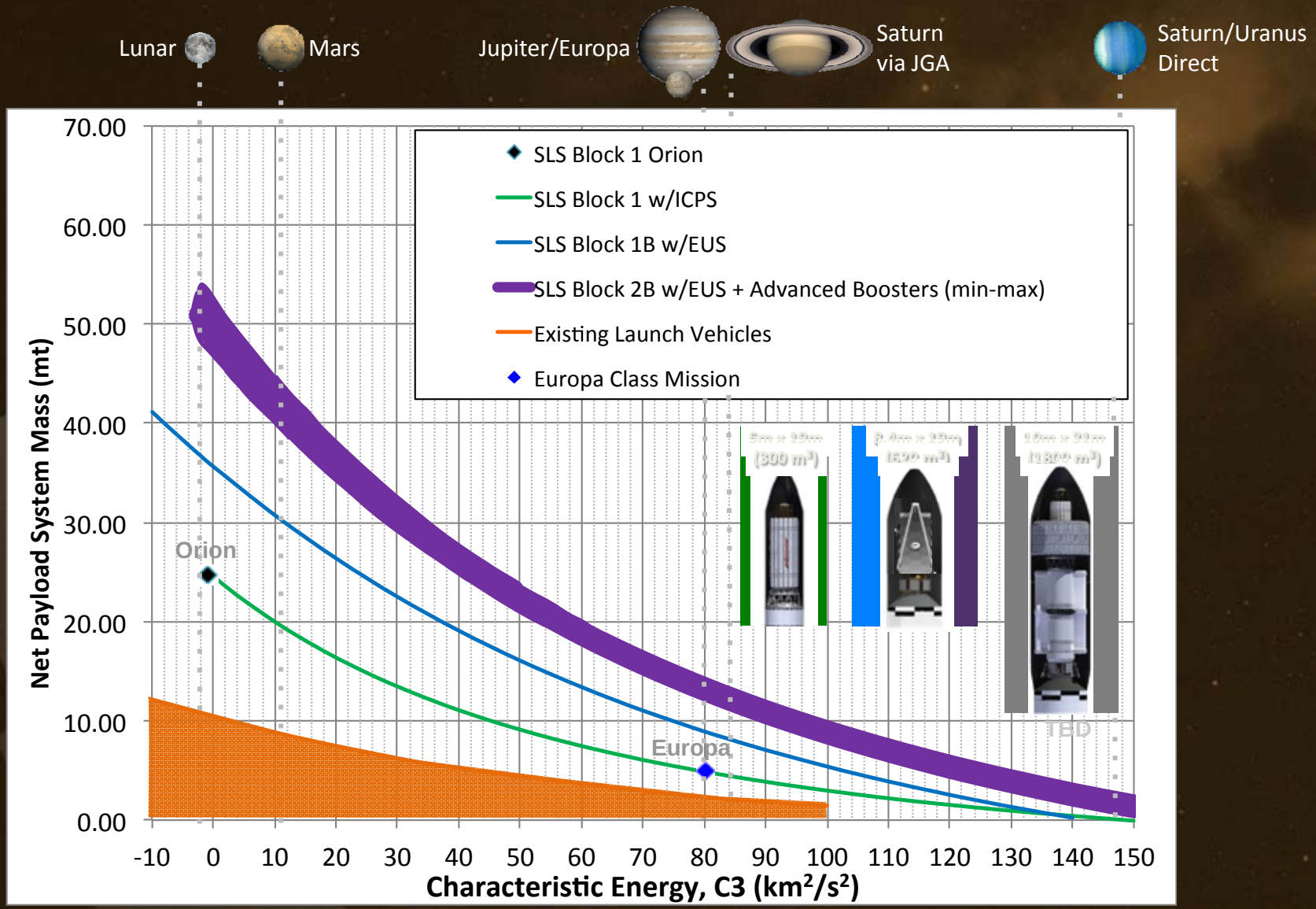
SLS Vehicle Performance



SLS Payload Configurations

Mission concepts with 5m fairing

Europa Clipper

total mission volume
= ~ 300m3
www.nasa.gov/sls

Mission concepts with Universal Stage Adaptor (includes additional payload capability)

Orion with EAM

total mission volume
= ~ 400m3

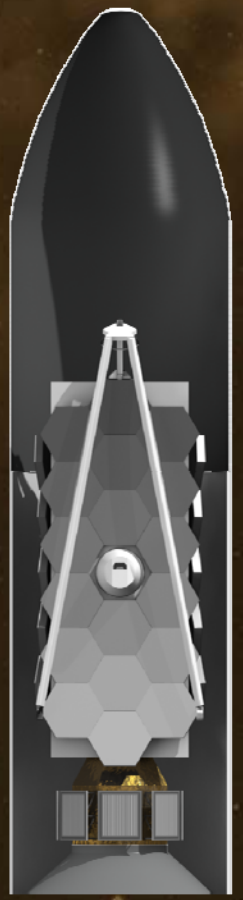
Orion with ARV

total mission volume
= ~ 400m3

5m fairing w/Robotic Lunar Lander & EAM

total mission volume
= ~ 600m3

Mission concepts with 8m and 10m fairings



8m fairing with ATLAST

total mission volume
= ~ 1200m3

10m fairing w/notional Mars payload

total mission volume
= ~ 1800m3

Upcoming Industry Forecast

Bryan Barley/XP50

ADG Task Award Process

Industry

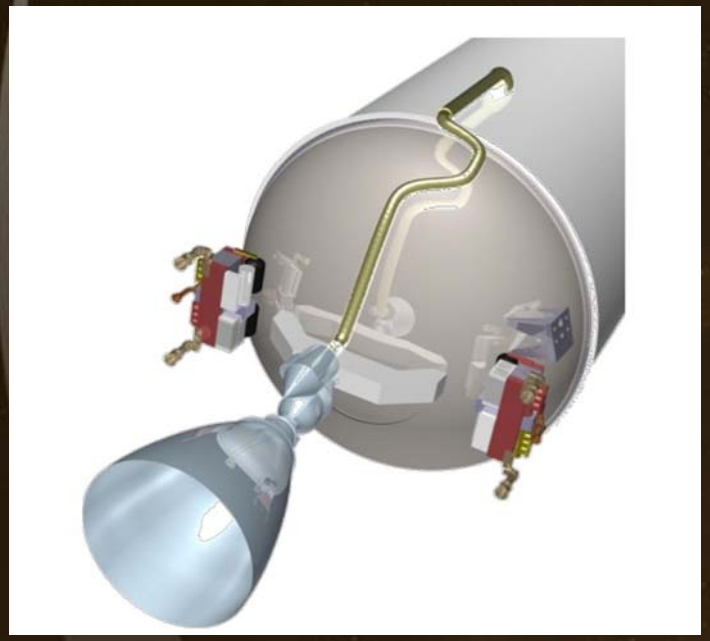
- Awards: Multiple
- Period of Performance: 1 year base (up to 18 months base period allowed), one 1 year option
- Type Solicitation:
  - NASA Research Announcement (NRA)
  - Designed for contracts or cooperative agreements
- Type of Contract: Firm Fixed Price (FFP)
- Anticipated Solicitation Announcement: FY15
- Anticipated ATP: FY16

SLS Advanced Development Group Technology Focus Areas

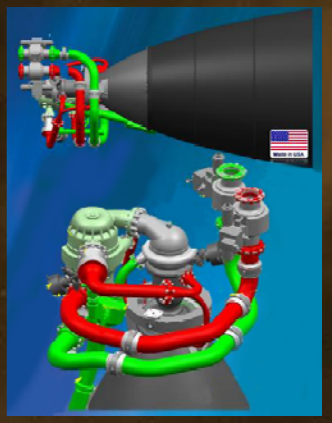
- SLS Industry Task Focus Areas
  - Exploration Upper Stage (EUS)
    - Light weight structures and materials, including composites
    - Advanced LOX/LH2 engine
    - Cryogenic storage for long duration missions
    - Advanced/Additive Manufacturing (Selective Laser Melting)
  - Universal Stage Adapter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

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)

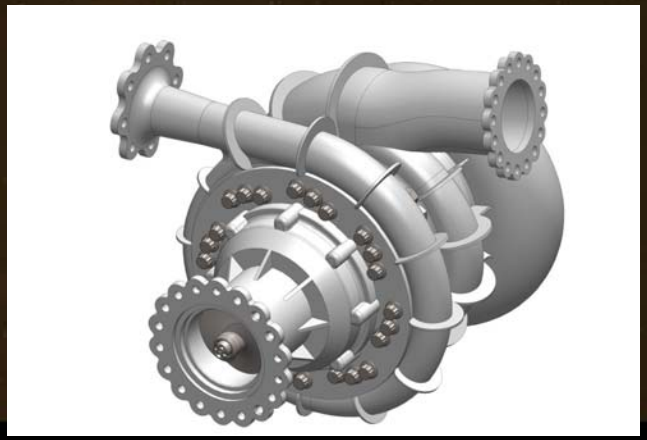


IVF (ULA)



Augment Expander Cycle Engine Concept (Aerojet)

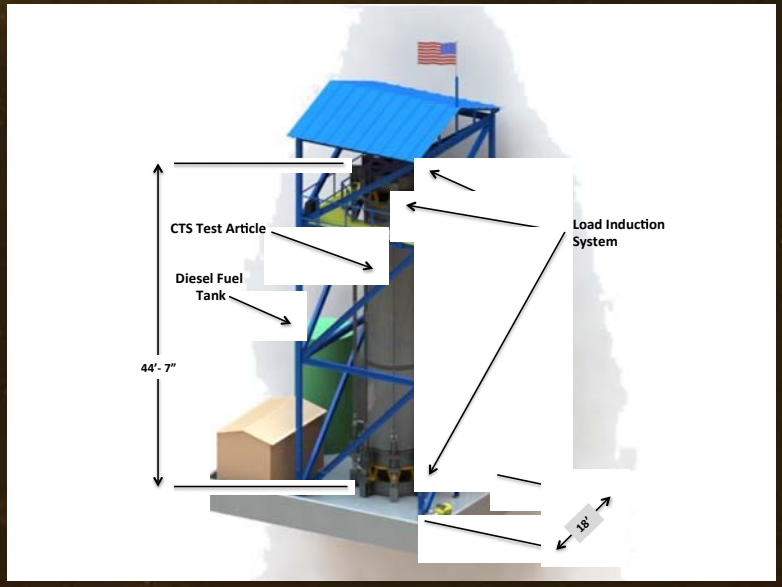
SLM Inconel 718 LOX Valve (Moog)



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 expend- able 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.
  - Deliveredf 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.

Previous Significant Accomplishments - Industry

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

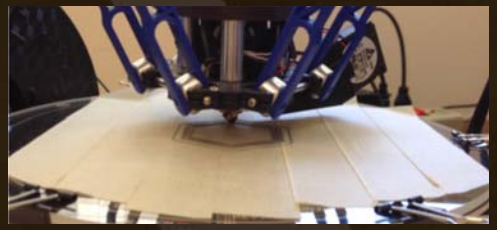
Focus on these calls is based on the needs for Block 1B and the reasonable projection of readiness to implement at that time

ADG Examples (In-House)

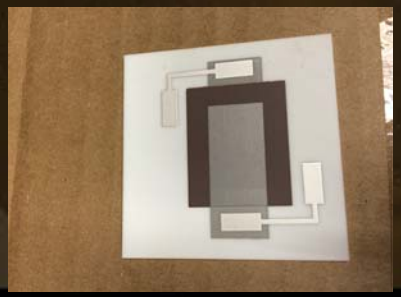
Hexavalent Chromate-Free Primer

Low-Profile Diffuser

LOX/H2 SLM Injector Testing



Additive Manufacturing 3-D Printer



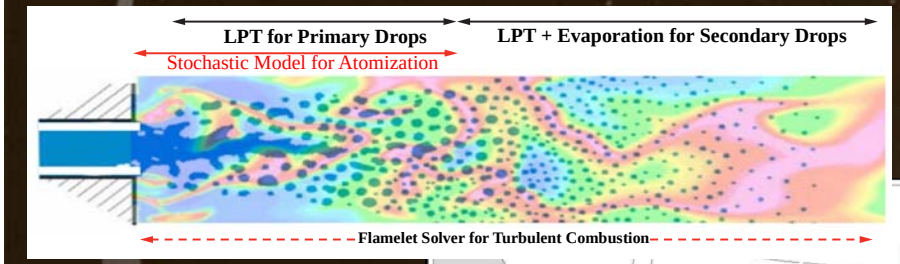
Ultra-Capacitor

SLM Ti6-4 Turbopump Impeller

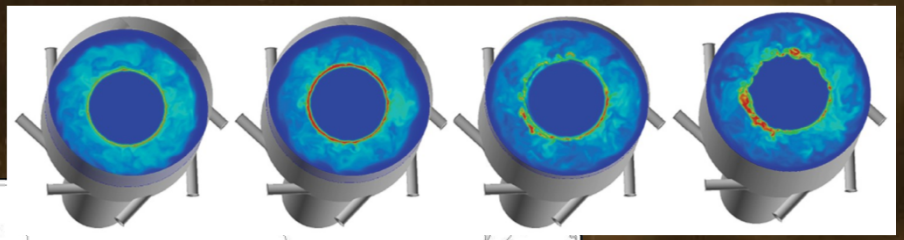
Previous Significant Accomplishments (In-House)

- **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

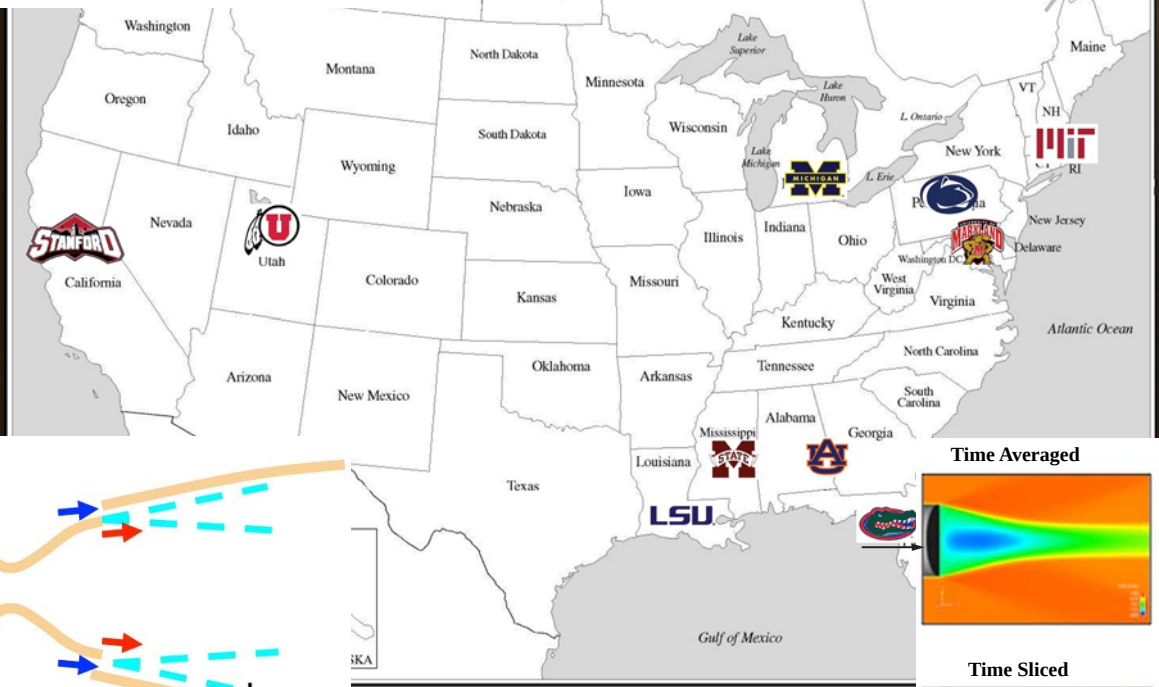
ADG Examples (Academic)

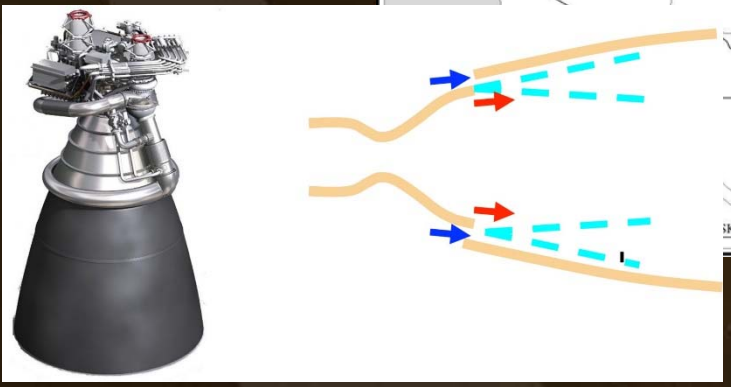


Injector Subcritical Atomization Simulation (U of FL)

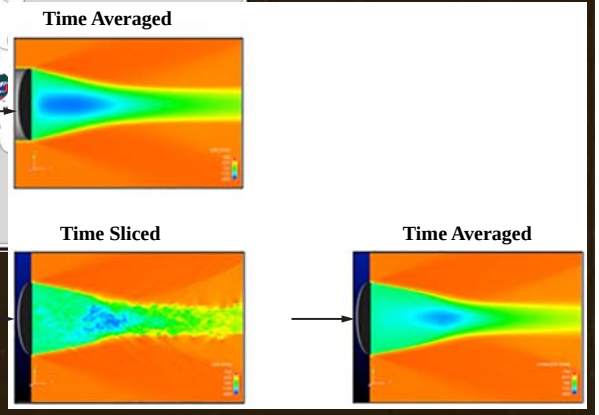


Unsteady Burning in Coaxial Element (U of Michigan)





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.

Closing Comments & General Q&A

Dr. Fred Bickley/XP50