National Aeronautics and Space Administration

NASA's Liquid Oxygen/ Hydrocarbon (LOX/HC) Engines

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Space Launch System

Powering the Future of Exploration

NASA Experience with LOX / RP-1 Propulsion

- **NASA systems**
  - RP-1 experience spans a significant period of Agency history
  - Strong heritage of hardware design, development, analysis and test exists within the agency
  - Marshall Space Flight Center (MSFC) has significant capabilities in supporting disciplines such as materials, manufacturing, and test
- **Industrial base strengthened through NASA programs and technology transfer**
  - History of partnering with industry in various capacities has further advanced the U.S. knowledge base
  - Transfer of key design codes, test and materials data, analytical results
  - Recent F-1 disassembly work, both at MSFC and at Aerojet Rocketdyne, ensures the next generation has an understanding of RP-1 propulsion

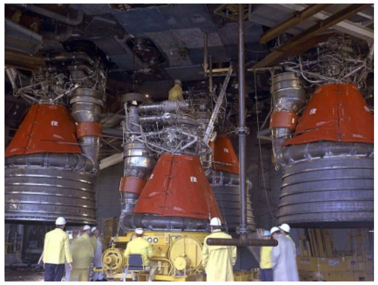
History of LOX/RP-1 Engine Development
MSFC Partnered with Industry

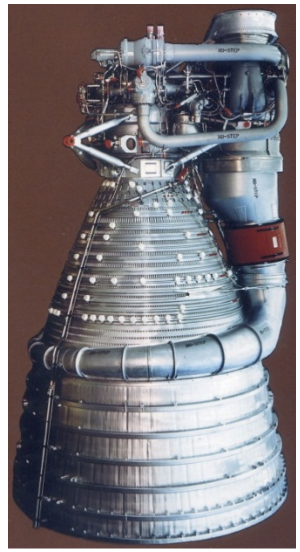
1955–1973
F-1
Gas Generator Cycle
Prime: Rocketdyne

Flew on Saturn V

F-1A
In development at the end of the program

Upgraded Turbomachinery



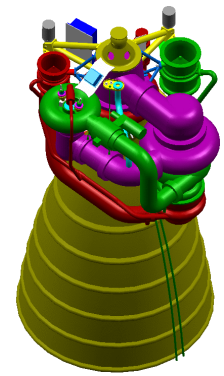


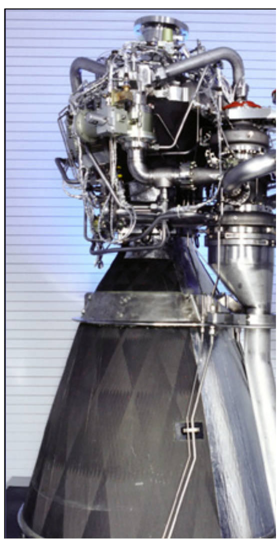
2001–2004
TR107
Ox- Rich Stage Combustion
Prime: TRW

Engine to CoDR fidelity

Subscale (5k) Pintle Test at Purdue

250 k Preburner Built, not Tested



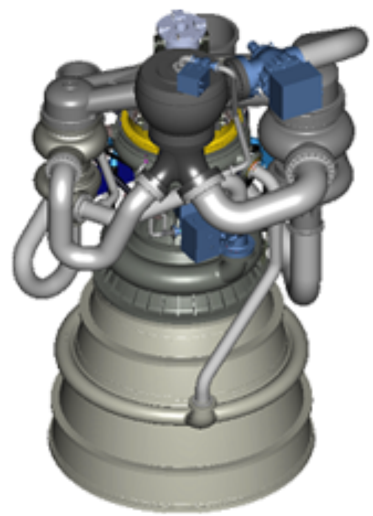


1996–2001
Fastrac (MC-1)
Gas Generator Cycle
Government Design
Hardware Prime: Summa
Vehicle Prime: Orbital

Engine was Fully Developed

Engine assembled into the X-34 vehicle but did not fly

2001–2004



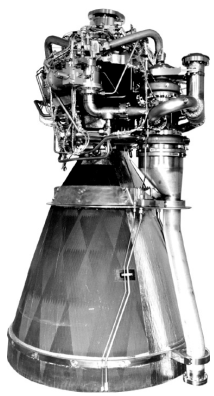
RS-84
Ox-rich Stage Combustion
Prime: Rocketdyne

Engine to IDR
(nearly CDR fidelity)

Significant subscale testing completed

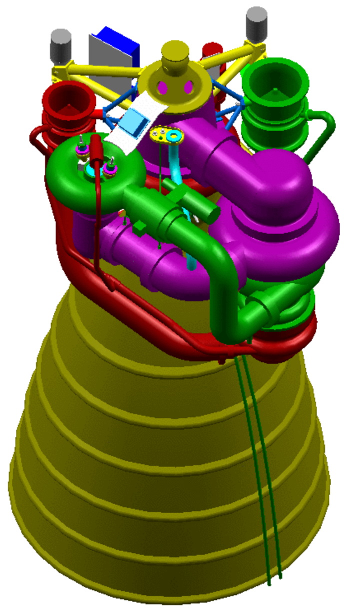
History of LOX/RP-1 Engine Development

Engine Size Comparison



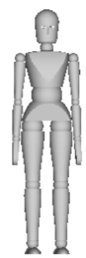
Fastrac

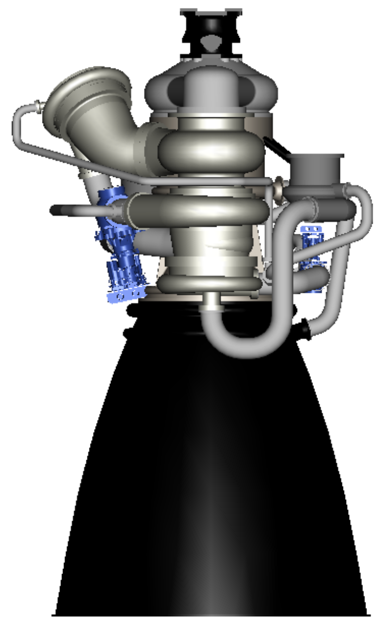
Tsl = 60 Klbf
Tvac = 63.9 Klbf
Isp (sl) = 300 sec
Isp (vac) = 314 sec
Pc = 652 psia
Wt = lbm
T/W (sl/vac) = / L ="
MR = 2.17



TR107

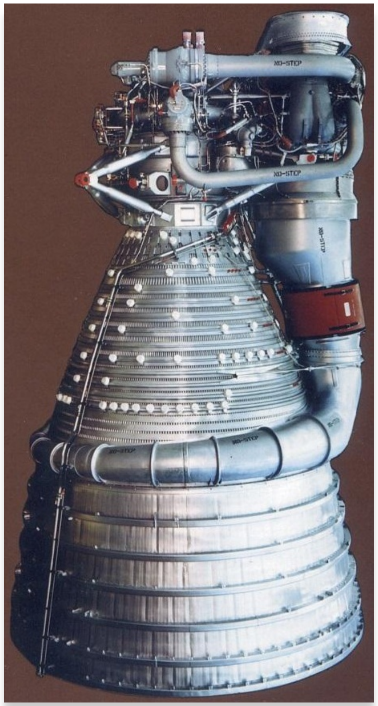
Tsl = 1,000 Klbf
Tvac = 1,074 Klbf
Isp (sl) = 300 sec
Isp (vac) = 327 sec
Pc = 2500 psia
Wt = 11,300 lbm
T/W (sl/vac) = 88 / 95
L = 180"
MR = 2.7





ORSC-RS84

Tsl = 1,050 Klbf
Tvac = 1,155 Klbf
Isp (sl) = 305 sec
Isp (vac) = 335 sec
Pc = 2700 psia
Wt = 15,925 lbm
T/W (sl/vac) = 65 / 73
L = 168"
MR = 2.7



F-1

Tsl = 1,522 Klbf
Tvac = 1,748 Klbf
Isp (sl) = 265.4 sec
Isp (vac) = 304.1 sec
Pc = 982 psia
Wt = 18,616 lbm
T/W (sl/vac) = 82 / 94
L = 220"
MR = 2.27

History of LOX/RP-1 Propulsion

Fastrac Engine and Stage Testing and Integration

	HTF	PTA	Alfa 1	ALL
Total Tests	35	5	17	57
Total Hot Fires	27	3	12	42
Total Main Stage Tests > 5 sec	15	2	8	25
Total Seconds	428	138	322	888
Main Stage Sec	330	126	276	732
Early Cuts for Engine Causes	9	0	2	11

History of LOX/RP-1 Propulsion

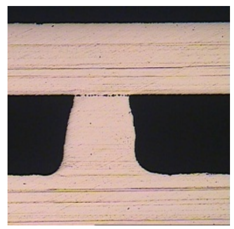
Unique Test Facilities Aid Industry

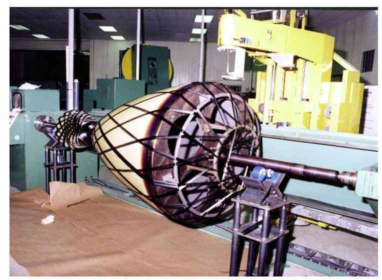
East Test Area

- Subscale and component level high-pressure testing of injectors, nozzles, pumps, thrust chambers
- TS115, TS116

Materials Lab

- Failure investigation
- Comprehensive materials testing
- State of the art welding, brazing techniques
- Structured light
- Advanced manufacturing





North Test Area

- Unique, low-cost, quick-turnaround fluid flow tests
- Turbine, inducer, pump, and nozzle test facilities

Stennis Space Center

- LOX/RP-1 engine systems testing
- LOX/RP-1 large component testing
- Stage testing

Component Development Area

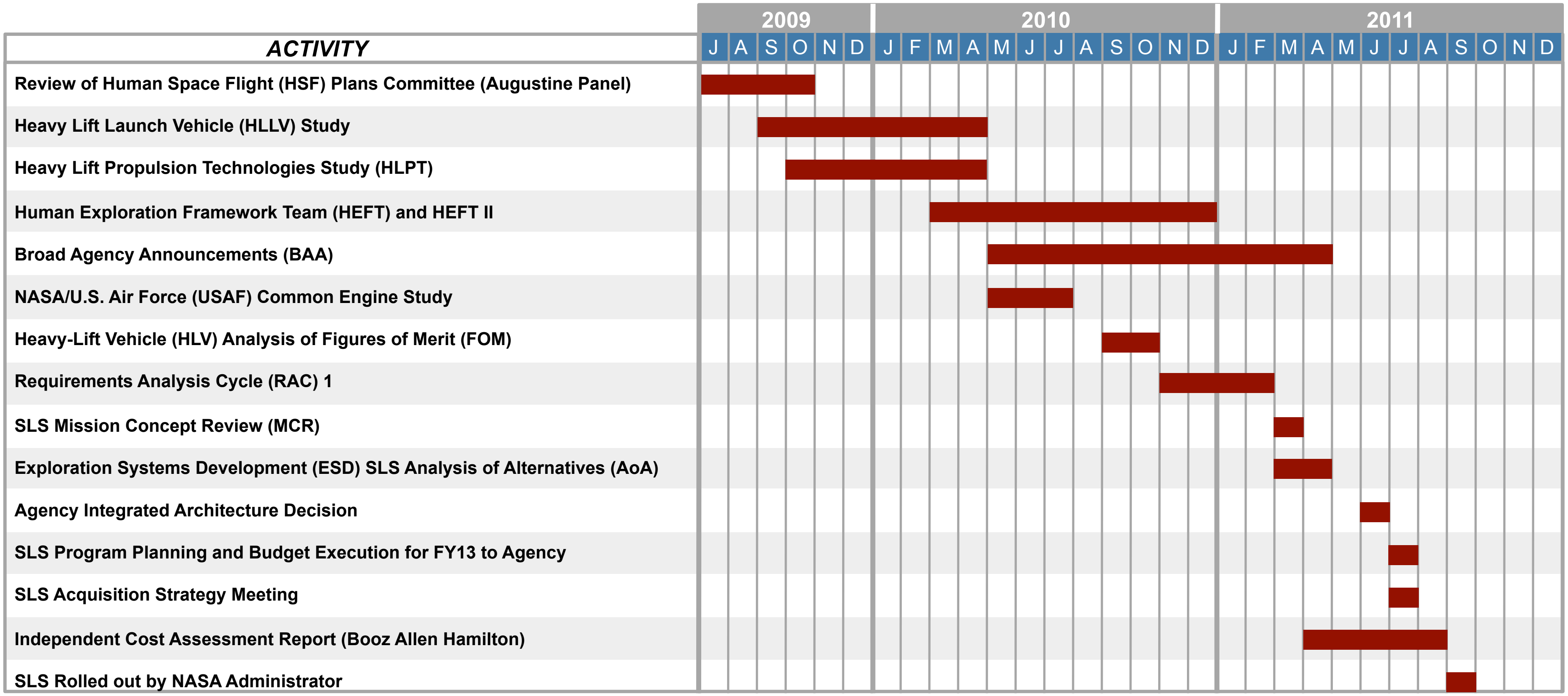
- Unique propulsion system component technology assessment
- Focused on valve, regulator, solenoid, and seal development

History of LOX/RP-1 Propulsion

Recent F-1 Disassembly

Prepares Government and Industry Workforce for SLS Advanced Booster NRA

Studies & Activities Leading to the SLS Decision



Engineering and Business Analyses Validated SLS Architecture Selected by the Agency

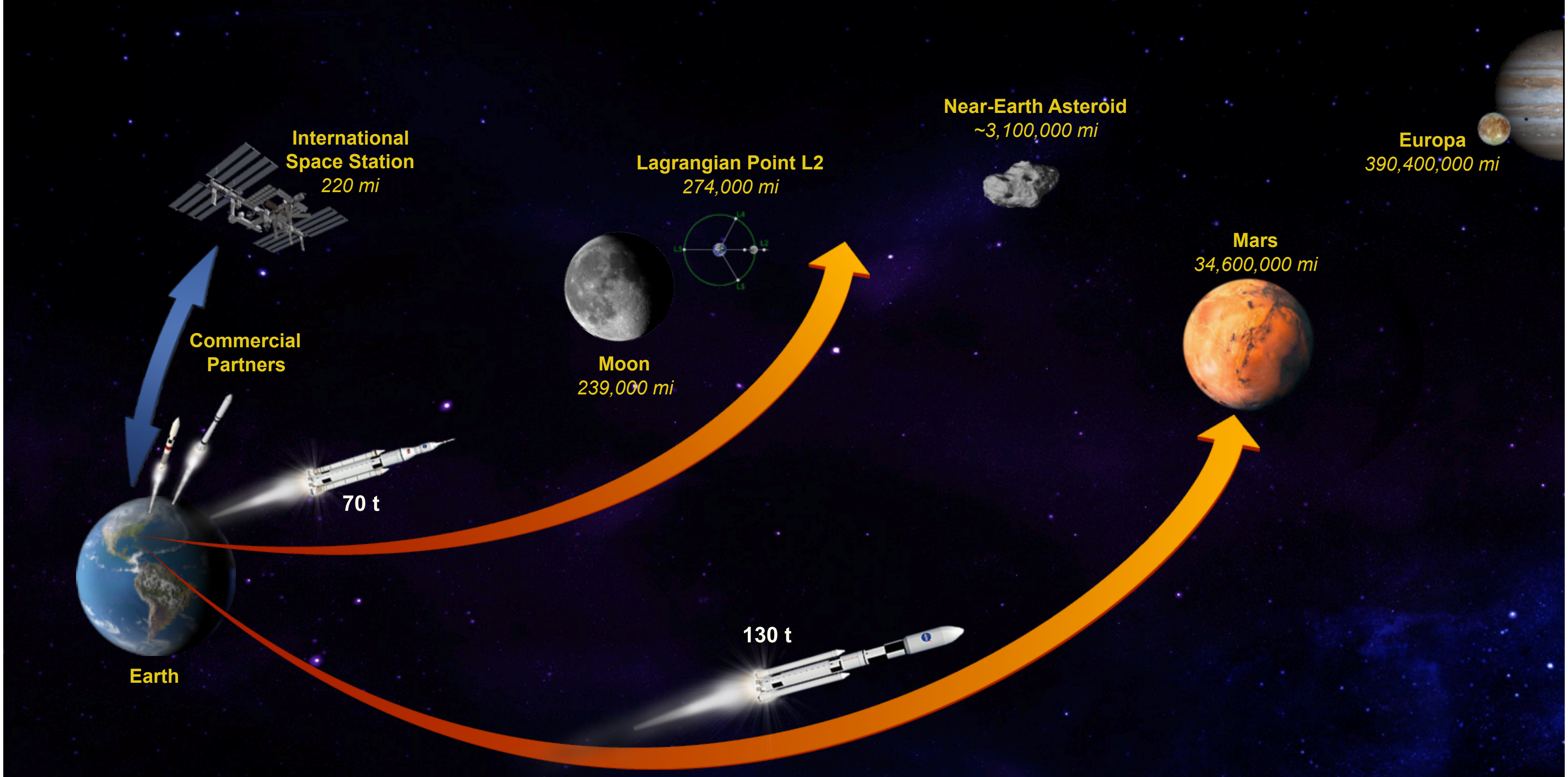
NASA Authorization Act of 2010

- **The Congress passed and the President signed the National Aeronautics and Space Administration Authorization Act of 2010.**
  - Bipartisan support for human exploration **beyond low-Earth orbit (LEO)**

- **The Law authorizes:**
  - Extension of the International Space Station (ISS) until at least 2020
  - Strong support for a commercial space transportation industry
  - **Development of Orion Multi-Purpose Crew Vehicle (MPCV) and heavy lift launch capabilities**
  - A “flexible path” approach to space exploration, opening up vast opportunities including near-Earth asteroids and Mars
  - New space technology investments to increase the capabilities **beyond Earth orbit (BEO)**

This rocket is key to implementing the plan laid out by President Obama and Congress in the bipartisan 2010 NASA Authorization Act.
— NASA Administrator Charles Bolden
September 14, 2011

The Future of Exploration



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.

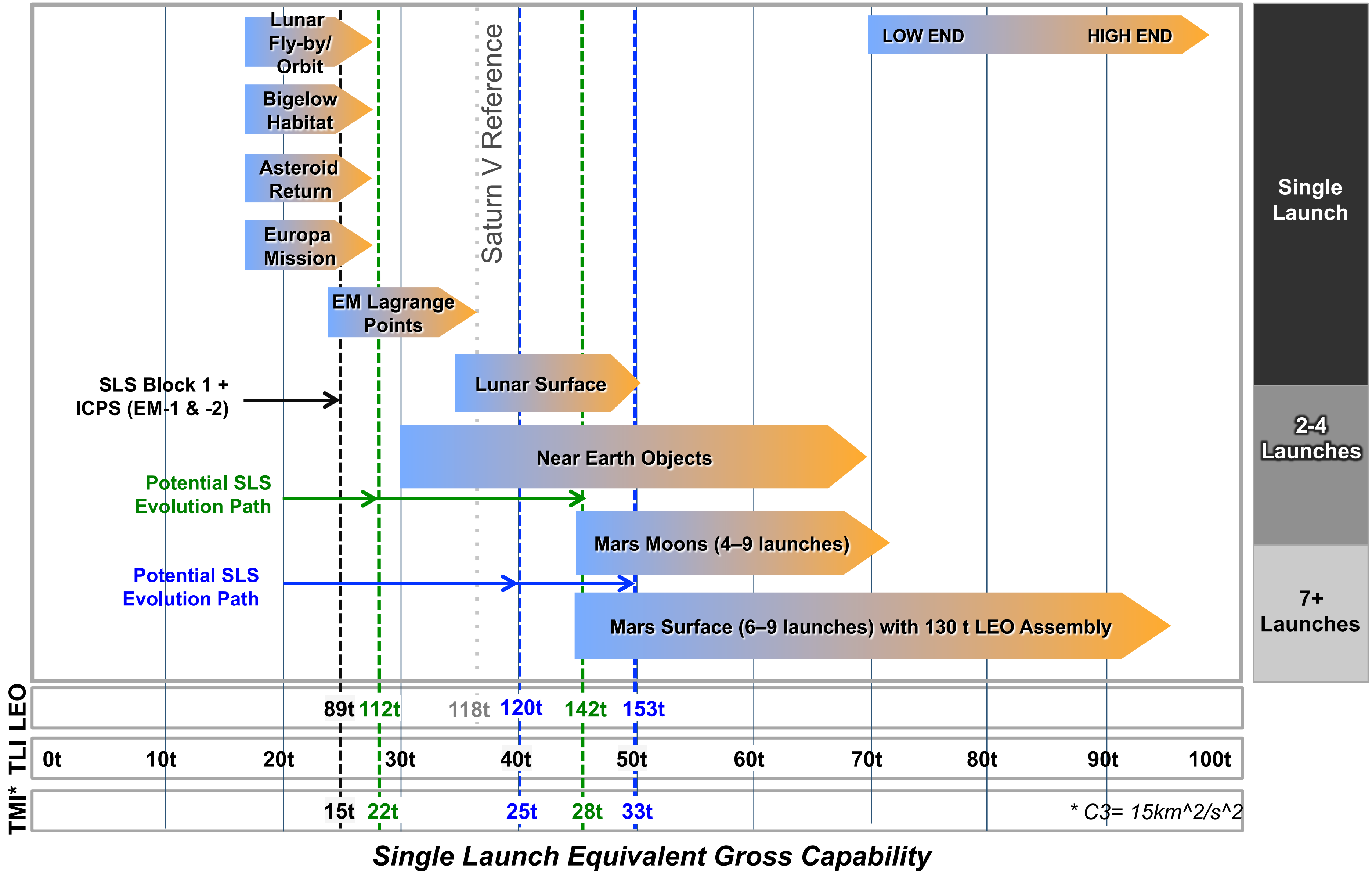
President Obama's Accomplishments for NASA
May 22, 2012

SLS Driving Objectives

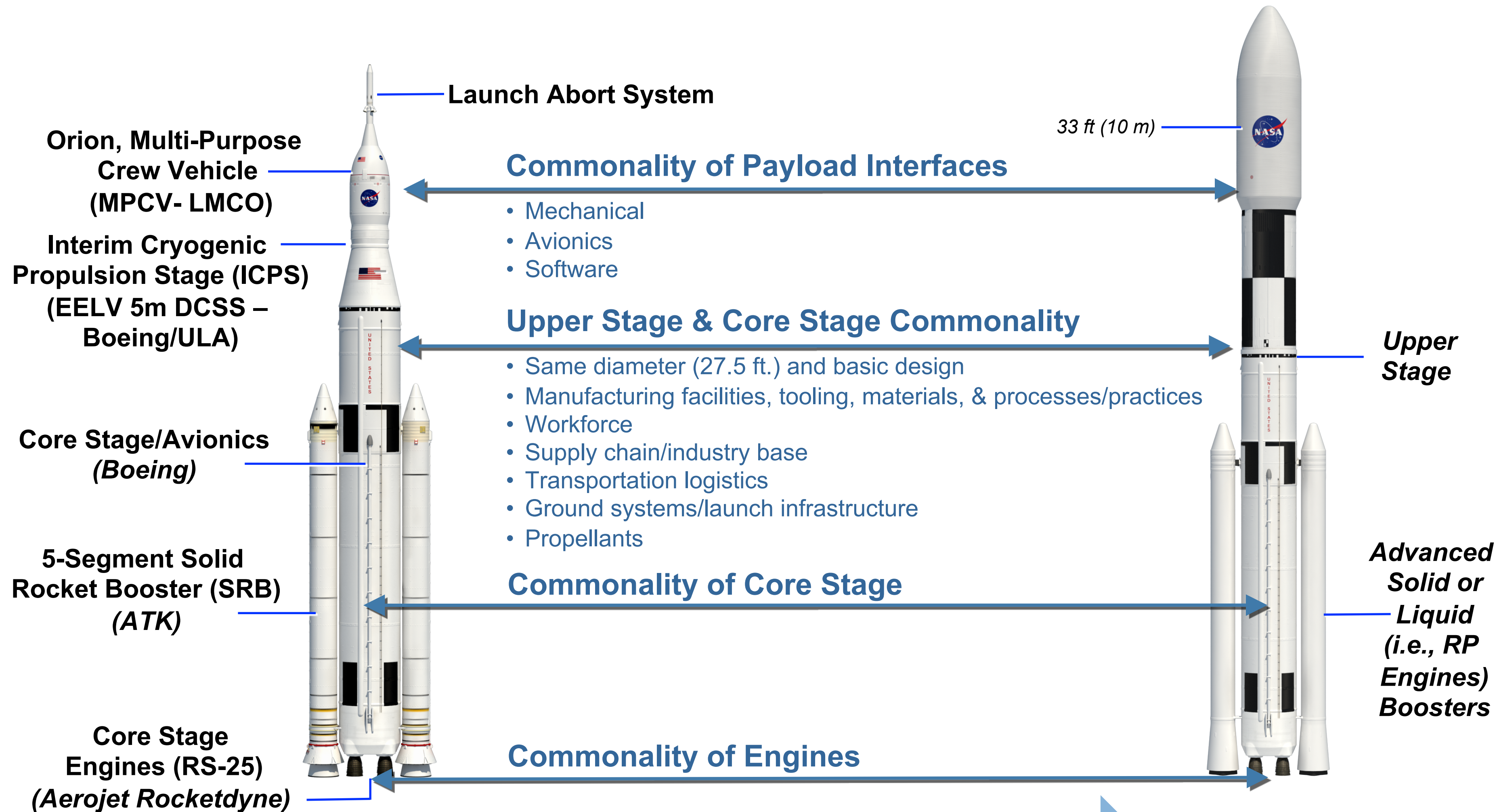
- **Safe**
  - Human-rated to provide safe and reliable systems
  - Protecting the public, NASA workforce, high-value equipment and property, and the environment from potential harm
- **Affordable**
  - Maximum use of common elements and existing assets, infrastructure, and workforce
  - Constrained 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

Powerful, Versatile, Evolvable

Potential SLS Mission Capture and Evolution



SLS Block Commonality

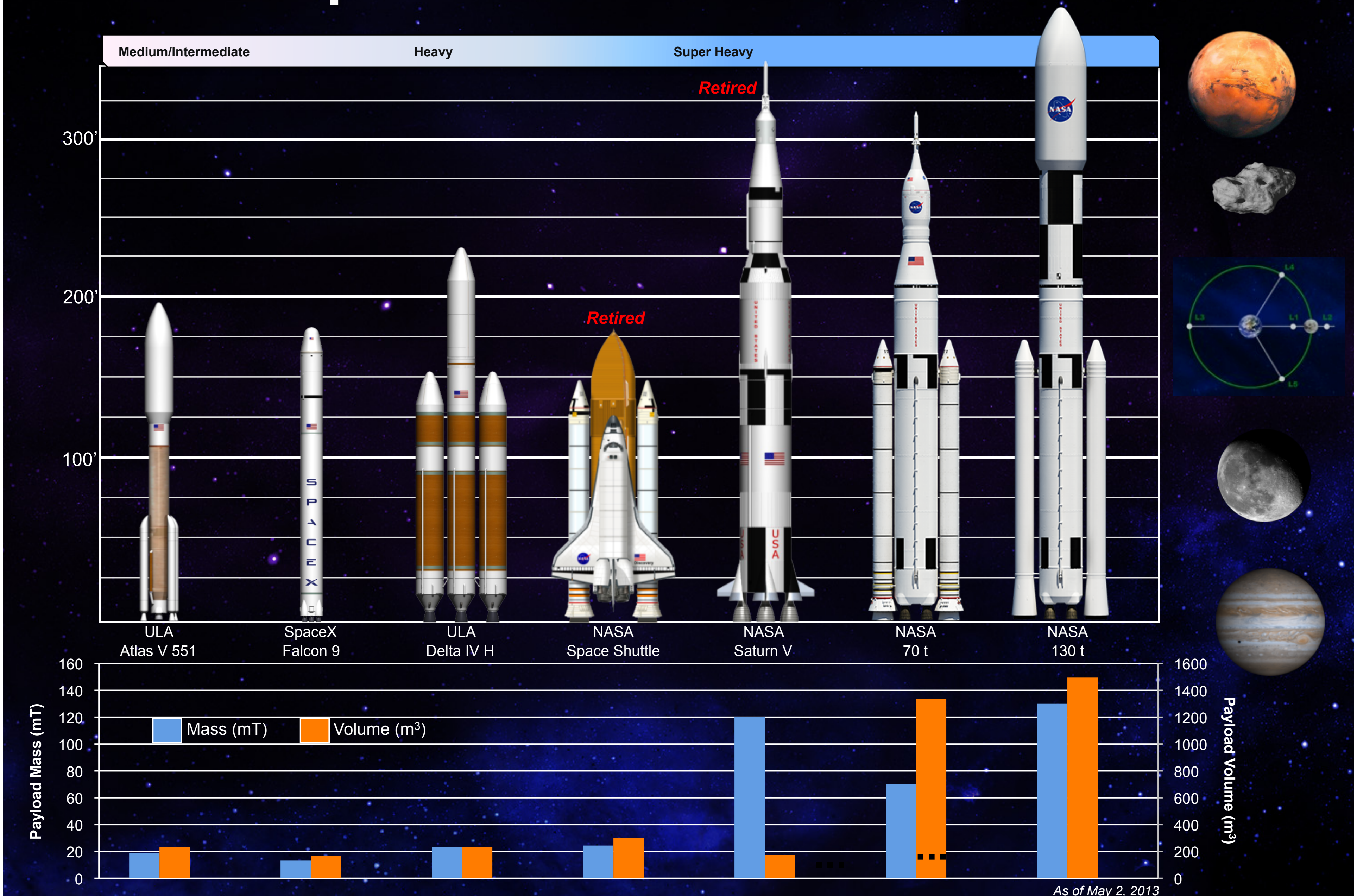


Block 1
Initial Capability, 2017-21
70 metric ton Payload

Evolutionary Path to Future Capabilities
- **Minimizes unique configurations**
- **Allows incremental development**

Block 2 Capability
130 metric ton
Payload

Most Capable U.S. Launch Vehicle



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 ▼	EFT-1 Launch ▼; KDP D ▼	KDP E ▼; EM-1 Launch ▼	EM-2 Launch ▼; KDP F ▼	
Human Space Flight Project Reviews	MCR ▼ ✔ 2011	SRR/SDR ▼ ✔ 2012	FOCUSED ON → PDR ▼ 2013	CDR ▼ 2015	SIR ▼ 2016; FRR ▼ 2017	▼ 2021	

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

[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

A National Infrastructure Asset

For Beyond-Earth Orbit Exploration

2017

www.nasa.gov/sls