SPACE LAUNCH SYSTEM

SSME to RS-25: Challenges of Adapting a Heritage Engine to a New Vehicle Architecture

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Overview

The Space Launch System (SLS) program was initiated in 2010-11 following the cancellation of the Constellation program and retirement of the Space Shuttle.

- The SLS vehicle is intended to provide next-generation heavy-lift cargo and crew access to space to enable exploration missions beyond low Earth orbit.
- A key constituent of the SLS vehicle is the RS-25 engine, also known as the Space Shuttle Main Engine (SSME).
  - The RS-25 was selected to serve as the main propulsion system for the SLS core stage with the 5-segment solid rocket boosters.
  - It's selection was primarily based on the system maturity and extensive experience gained from 135 missions and numerous tests conducted during its 40 year development and operational lifespan.
  - Another factor in the RS-25 selection was the immediate recovery of 16 flight engines and two development engines from the Shuttle program that could be used for the first four SLS flights.

RS-25 Pros and Cons

- Although the selection of the RS-25 had many programmatic advantages gained by avoiding the cost and time required to develop a "clean sheet" engine, the technical challenge of adapting the heritage engines to support the SLS vehicle has not been a simple activity.
  - Rocket engines are not "plug-and-play" from one vehicle to another.
- With regard to the rest of the vehicle, emphasis was made to treat the engine as a "black box" that was to be primarily static in terms of design and operation.
  - While this emphasis was largely respected in order to realize the savings in cost and schedule, some changes to the engine baseline were necessary in order to mitigate concerns in the following areas:
    - Loads and environments
    - Interface conditions
    - Component obsolescence
  - An overview of these adaptation changes will comprise the majority of this paper.

Laying the Foundation for SLS

The SLS program is managed at the Marshall Space Flight Center (MSFC) and is one of three collaborative NASA enterprises supporting crewed space exploration, the others being:

- Orion Multi-Purpose Crew Vehicle (MPCV), managed at Johnson Space Center (JSC)
- Ground Systems Development & Operations (GSDO), managed at Kennedy Space Center (KSC).

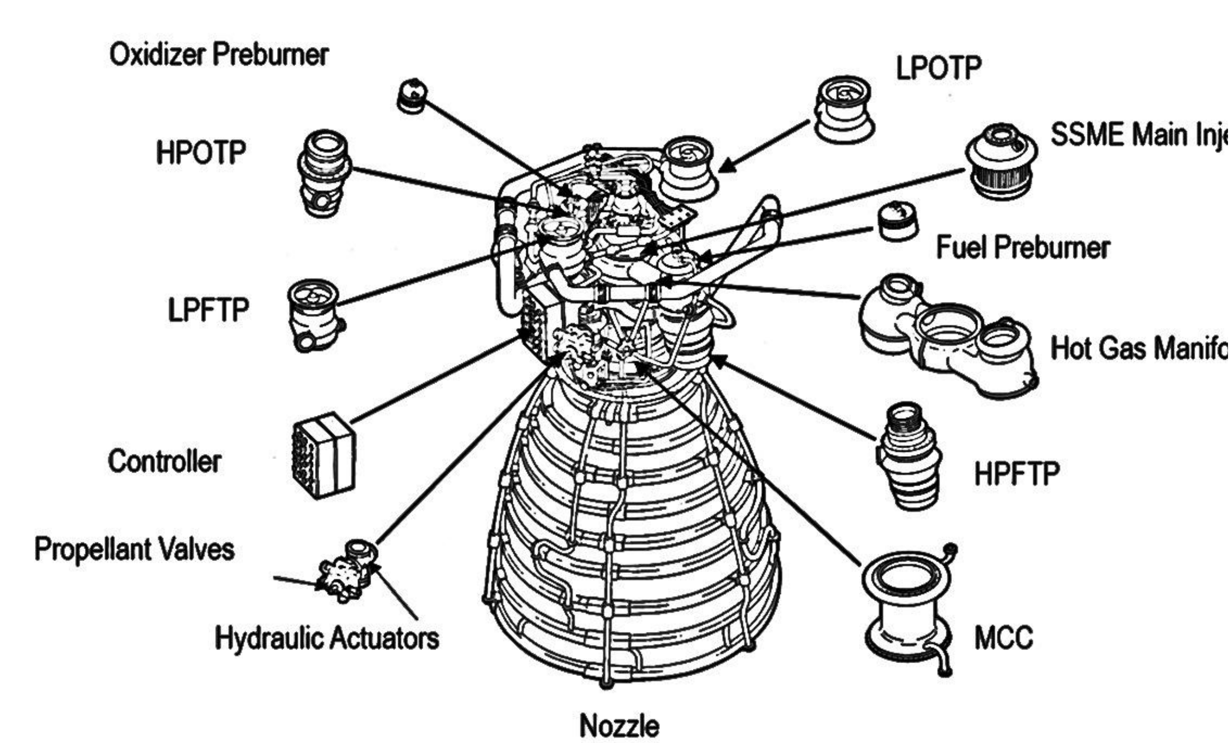
Within the SLS program structure, management responsibility is partitioned along key hardware systems into separate elements:

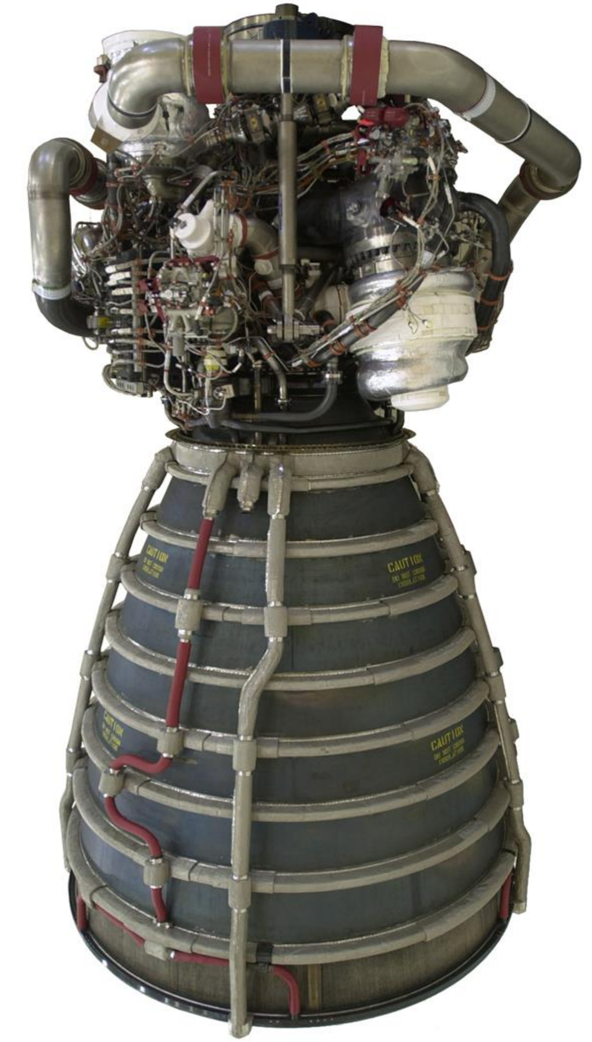
- The Liquid Engines Office (LEO), responsible for the RS-25 core stage engine and the upper stage engine.
- The Stages element office, responsible for the core stage and Exploration Upper Stage (EUS).
- The Boosters element office, responsible for the solid rocket boosters.
- The Spacecraft/Payload Integration and Evolution (SPIE) office, responsible for the Interim Cryogenic Propulsion Stage (ICPS) and advanced development.
- Ground Operations Liaison Office (GOLO), responsible for coordinating integration activities between SLS and GSDO.

Liquid Engine Description

The Core Stage Engine (CSE):

- RS-25 / SSME
- Demonstrated high performance, high reliability staged-combustion cycle LOX / LH_2 engine
    - 512K lbs (2277 kN) vacuum thrust @ 109% RPL
    - 452 sec average vacuum I_{sp}





Adapting Heritage SSME for SLS

- **Immediate advantages**
  - Rapid availability of development hardware for tests
  - Rapid availability of flight hardware
  - Extensive experience base for SSME
- **Immediate disadvantages**
  - Limited development hardware and schedule for system tests
  - Limited life remaining on flight assets
  - Minimal useful hardware spares inventory

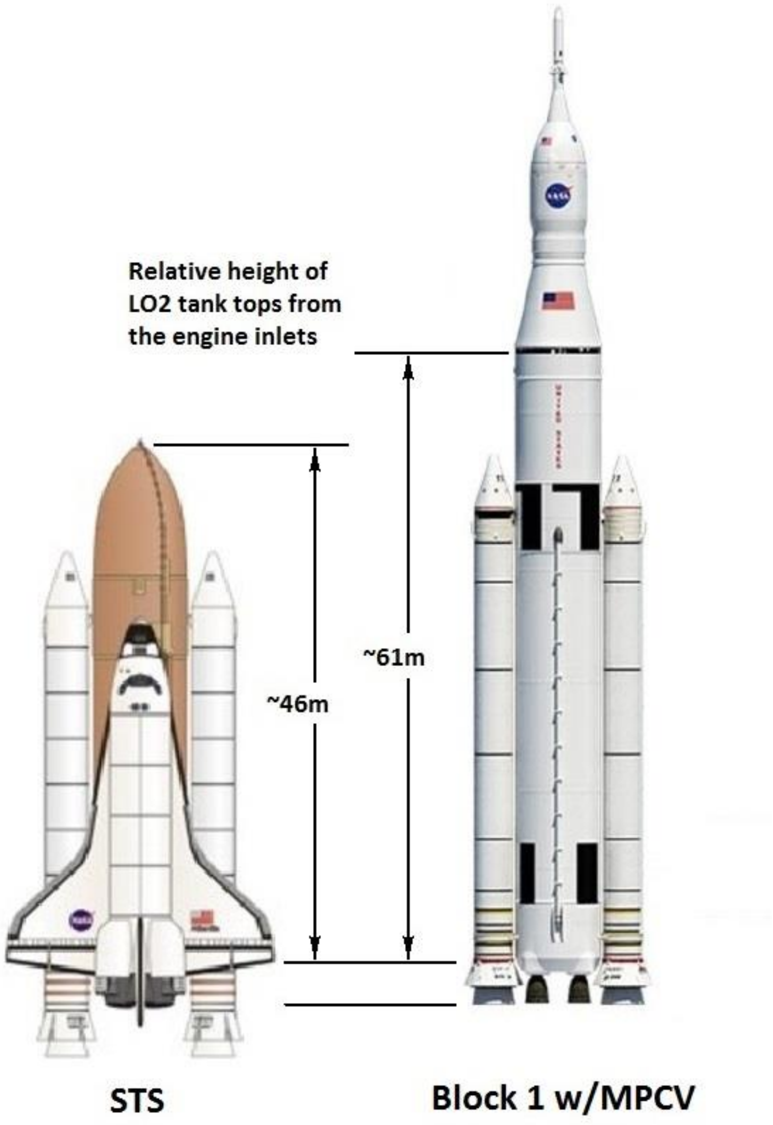
- **The primary focus for adapting the heritage SSME configuration involved the following:**
  - Compliance with allocated SLS vehicle and program requirements.
  - Replacing the obsolete engine controller unit (ECU) with a modern system.

Compliance with SLS Requirements

- **As stated earlier, emphasis was made to inhibit technical requirements that would impact the engine baseline design.**
- **However, integrating the RS-25 to the SLS vehicle required compliance in the following areas:**
  - <u>Interface definition with the core stage</u>
    - Issue: High LOX inlet pressure / low LOX inlet temperature
    - Issue: Prelaunch fuel bleed flow
  - <u>Loads and environments</u>
    - Unless otherwise indicated, it was assumed that the STS (Shuttle) loads and environments enveloped those of SLS.
    - Issue: SRB radiant thermal environment
    - Issue: BSM exhaust impingement
    - Issue: CAPU exhaust impingement
    - Issue: Aft compartment thermal environment
  - <u>Design and construction standards</u>
    - Use of the "Heritage Exemption" for existing hardware

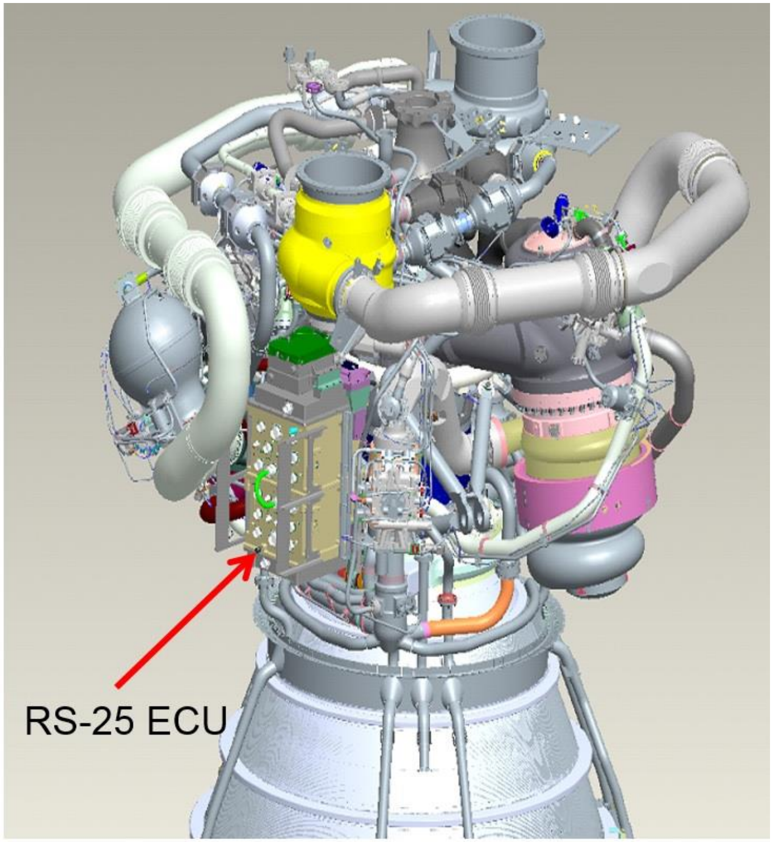
Examples

- **Low LOX Inlet Pressure**
  - Driven by increased vehicle length
- **Low LOX Inlet Temperature**
  - Coincident with low LOX inlet pressure
  - Mitigated by electric heaters
- **CAPU exhaust impingement / SRB radiant thermal environment / BSM plume impingement**
  - Mitigated by addition of nozzle ablative insulation to shield exposed area



RS-25 Engine Controller

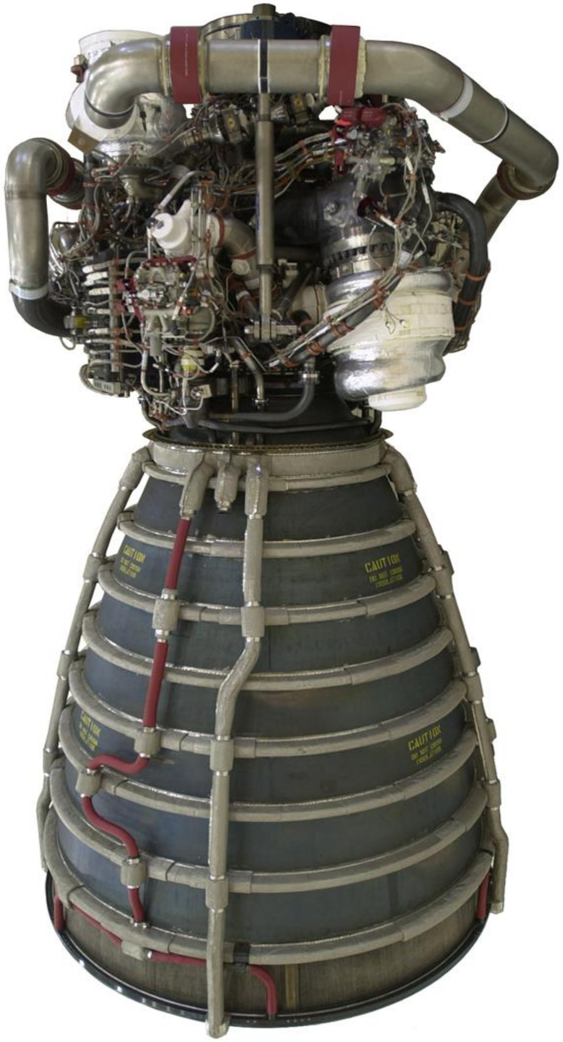
- **The only significant RS-25 component that required replacement was the ECU.**
  - Technologically obsolete and incompatible with the SLS vehicle power and data architecture.
- **The replacement design was able to leverage off work completed on the J-2X ECU.**
  - Offered savings of time and resources compared to a “clean sheet” design.
  - Significant challenges still encountered in adapting the J-2X ECU to the more complex RS-25 system.



- **The early initiation of development tests was enable by the use of non-flight Engineering Model (EM) controllers that were functionally equivalent to the flight units.**

Phases of RS-25 Activity for SLS

- **Adaptation (current)**
  - Adapt, certify and deliver residual RS-25 assets for initial SLS flights
    - New Engine Controller Unit (ECU)
    - New SLS Environments
  - Utilize SSC A1 test facility for single-engine testing.
  - 1st RS-25 flight set allocated to support SLS core stage green-run at SSC B-complex.
- **Recertification (planned)**
  - Incorporate affordability options and recertify upgraded system for continued SLS service.
- **Production Restart (planned)**
  - Initiate new production of updated RS-25 system



RS-25 Hotfire Program Underway with New Controller

Controller Installation
21 Oct 2014

Engine Hot-Fire Tests
- 9 Jan 2015 (500 sec)
- 28 May 2015 (500 sec)
- 11 Jun 2015 (500 sec)

All tests fully successful!

RS-25 Engine 2063 Build