National Aeronautics and Space Administration

SPACE LAUNCH SYSTEM

Core Stage Thrust Vector Control Systems Engineering Challenges in Reusing Heritage Hardware

Blake Stuart, John Wall, Jeb Orr, Jesse McEnulty, Pete Pektas

AAS Breckenridge
Feb 2-8th, 2023

Agenda

- Background
- Requirements Challenges
- System Design Challenges
- Performance Challenges
- Operational Challenges
- Conclusion
- Questions

Background

- **SLS Core Stage (CS) Thrust Vector Control (TVC) System leverages heritage hardware from the Space Shuttle Program as well as new hardware**
- **Integrating heritage, modified heritage, and new hardware is a challenging process**
- **Examples of the challenges that were overcome include:**
  - Re-qualifying heritage hardware to survive new shock and vibration environments
  - Certifying performance of extensively modified heritage hardware
  - Regenerating design insight due to lack of available heritage vendor data
  - Showing compliance to modern structural design standards
  - Translation of heritage requirements for analog avionics to modern digital avionics
  - Interfacing heritage mechanical hardware with newly designed avionics.

Requirements Challenges

- **Predicted Environments**
  - Higher than those used to qualify Shuttle hardware for flight
  - Required vibration isolators for Core Stage Auxiliary Power Unit (CAPU)
  - Drove requalification for TVC Actuator
    - Development testing showed resonance in TVC Actuator mechanical feedback
    - Necessitated design modification
- **Design and Construction Standards**
  - Time intensive assessment of heritage standards vs. modern ones
  - Caused multiple waivers to be generated
- **Translating Heritage Requirements**
  - Modernizing from analog to digital avionics, requirements like signal anti-aliasing were "lost in translation"
  - Lack of knowledge of heritage design intent
  - Absence of heritage vendor insight

System Design Challenges

- **Removal of Hydrazine**
  - Space Shuttle Solid Rocket Booster (SRB) and Orbiter Auxiliary Power Unit (APU) powered by hydrazine
  - CAPU powered by gHe and gH2
  - Eliminates hazardous operations with known carcinogen
  - SRB gHe APU development testing in early 2000s
  - Additional development and qualification testing to certify operation in gH2
- **Switch from Bootstrap to Gas Pre-charged Metal Bellows Hydraulic Reservoir**
  - Led to elevated hydraulic return pressures than those experienced on Orbiter or SRB
  - Required higher pressure proof and burst testing
  - New structural analysis required above and beyond what was done on heritage hardware
  - Precipitated additional waivers for environmental correction factors
- **Heritage Circulation Pump Vendor No Longer Available**
  - Changed installation from Orbiter to SLS Core Stage
  - No design insight from vendor
    - New installation resulted in change in operational behavior
    - Required acceptance test stand to be built
    - Development testing necessary to understand thermal performance

Performance Challenges

- **CAPU**
  - Cold gas (gHe – ground, gH2 – flight) spun turbine vs. hydrazine
  - Modified control valve design for higher flow rate vs. heritage
  - New control valves pilot operated rather than direct acting
  - Modified control scheme – 2 valve to single valve
  - Modified dual gas input (gHe and gH2) to common input and moved filter to inline separate component
  - Ultimately, multiple changes from heritage hardware baseline were required to achieve qualified design
  - Achieved excellent Green Run and Flight performance
- **TVC Command Response**
  - Heritage engine, gimbal joint, TVC Actuators + new structure
  - Results from CS Green Run tests didn’t meet predictions/expectations
  - Discussed in detail in later presentations

Operational Challenges

- **CAPU Lube Oil**
  - Update to heritage procedure
  - Oil left in gearbox after de-service
  - Re-service added appropriate amount, but didn't account for residual
  - Excess oil can lead to turbine speed degradation and overheating
  - Corrected procedure but required unplanned operation on flight hardware
- **New Hydraulic Ground Support Equipment (GSE)**
  - Operational issue allowed vacuum condition in return lines
  - Potential to cause damage to flight hardware
  - Determined to be non-issue based on performance
  - New main pump mounting orientation prevented seal drain examination
- **Circulation Pump GSE Power**
  - Heritage pumps powered from Orbiter on-board power
  - SLS powered from ground
  - Much longer cable runs from GSE power supply
  - In-rush current effects caused over-voltage protection trips during pump start up

Conclusion

- **In general, the reuse of heritage hardware:**
  - May be a cost and schedule saver
  - May lead to increased risk to cost, schedule, and performance, if modifications to heritage design are not limited or well thought out
  - May lead to a surprise or two along the way
- **Changes to environments can impact reusability or at least drive analysis and test**
- **Translation of heritage requirements necessitates intimate design knowledge of both:**
  - How the hardware was used in the heritage application
  - How the new program intends to use the heritage hardware
- **A thorough analysis and test program proved essential to successful integration of the SLS Core Stage TVC system**

Questions