A Framework for Assessing the Reusability of Hardware (Reusable Rocket Engines)

> Rhonda Childress-Thompson NASA Marshall Space Flight Center

Dr. Dale Thomas Dr. Phillip Farrington The University of Alabama in Huntsville

December 5, 2016

Introduction

- Renewed interest in reusability
- Reusability Defined
- Importance of Reusability
- Areas that Limit Successful Implementation
- Factors to Consider for Incorporating Reusability











Reusability

• Reusability/Reusable Defined (for space applications)

• Any space flight hardware that is not only designed to perform multiple flights, but actually accomplishes multiple flights.

Importance of Reusability

- Permits inspections of flight hardware
- Allows development of databases for future endeavors
- Validates ground tests and analyses
- Allows the expensive hardware to be used multiple times

Roadblocks & Limitations

- Performance has been the driving requirement
- Benefits of reusability have not been validated
- Industry standards do not exist
- History is limited for reusable hardware (i.e. Space Shuttle, Space Shuttle Main Engine (SSME) and Solid Rocket Booster (SRB)
- Expendable hardware is less costly

Roadblocks & Limitations

 Payload capacity for a reusable booster is reduced by 1/2 to 2/3 that of an expendable booster of the same weight

Reusable Feature	Penalty (approx % of Return Weight)
Reentry Heat Protection Integral or separate shield	10
Deorbit Propulsion and Propellants Much lower thrust than ascent	3
Descent Deceleration Aero surfaces and/or propulsion with propellants	15
Landing Systems Landing gear, aero surfaces and/or parachutes	10
Rapid Servicing Access doors, removable components, Health Management System	2
Lower Stress Levels	5

Figure 1: Penalties for Reusability

- 1. Reusability Requirement Implemented at the Conceptual Stage
 - Forces a different way of thinking (accessibility & supportability)
- 2. Continuous Test Program
 - Allows improvement of characteristics such as life, producibility and operability
 - Enables investigation of anomalies
 - An active test program, coupled with actual flight data, enhances the reliability of the hardware
 - Builds engineering confidence

3. Minimize Post-Flight Inspections & Servicing to Enhance Turnaround Time

- Provide designs that allow minimum periodic maintenance
- Design-in preventive maintenance to reduce unplanned repairs
- Include integrated health monitoring to identify areas to service between flights
- Use off-the-shelf components whenever possible
- Look for opportunities to incorporate common components

4. Easy Access

- Components with higher failure rates and require more maintenance should be readily accessible.
- Assembly and disassembly must be simplified to improve turnaround time.
- Complex labor-intensive interfaces such as bolted joints with torque specification and patterns should be replaced with quick connect/disconnect fasteners to facilitate assembly and removal
- Minimize touch labor to reduce the possibility of induced failures.

5. Longer Service Life

- Focus on improving the inherent reliability of components with the highest failure rates to increase the Mean Time Between Repair
- Components with increased service life:
 - Require less
 maintenance
 - Shorten turnaround time



(Jue & Kuck 2010)

Figure 2: SSME Component Failure Rate

6. Minimize Impact of Recovery

- Return features make RLVs larger and more complicated
 - Retro or flyback propulsion
 - Parachutes or wings
 - Landing gear
 - Thermal protection
- Retrieval should not impart any additional loads on the hardware.
- Recovery Cost
- Refurbishment Cost

7. Evolutionary vs. Revolutionary Changes

Designs should evolve from existing designs

- Limits development unknowns
- Allows incremental changes to improve the design
- Provides opportunity to increase reliability

Figure 3: SSME Reliability Improvements



7. Evolutionary vs. Revolutionary Changes

First Manned Orbital Flight	Full Power Level	Phase II Return-to-Flight	Block I	Block IA	Block IIA	Block II
Base Line Engine First Flight STS-1	Powerhead/Ducts HGM fuel bow liner mods LOX post support prins in FPB New fowmeler straightener LOX post shields HPFTP Kel-F seals Replaced slepped interstage seals with smooth Increased clearance to tip seal HPOTP Housing material changed (nco 903) LPFTP Turbine discharge tuming vane mod Avionics Nozzle Increased tube wall thickness Added slearan loop First Flight STS-6	 HPFTP Shot peened Fr Trees Large Coolant Discharge Orifices HPOTP Bearing Changes Damping Seals Two Piece Dampers MCC EDNi Reinforced Outlet Neck. Burst Diaphragm Drainline HPF Duct He Barrier Avionics/Valves Increased Strength MFV Housing Anti-Backlash Couplings Potled Wireways Tight Stack GCV Modified Pressure Sensor Cavity Improved Hot-Gas temperature Sensor Skin Temp Sensor added to Anti-food Valve First Flight STS-26R 	 Phase II+ Powerhead (Two Duct) Single Tube HEX HPOTP/AT First Flight STS-70 Thermocouples First Flight STS-75 	 Main Injector Modifications Programmed Secondary Faceplate coolant holes First Flight STS-73 	 Large Throat MCC Cast hiet/Outer Elbows 20 Hole Fuel Sleeves Block II LPOTP Block II LPTP Actuator Spool Material Upgrade Filtered Check Valves Pressure Sensor Improvements First Flight STS-89 Opened BLC holes First Flight STS-96 	 HPFTP/AT Main Fuel Valve First Flight STS-104 Advanced Health Mgmt System Real Tme Vibration Monitoring First Flight STS-117

- Continuous improvement implemented throughout the life of the program
- Demonstrated reliability > 0.9996
- Over 1,000,000 seconds of hot-fire experience
- Foundation developed for liquid propulsion

(Wofford 2010)

Figure 4: History of Major SSME Upgrades

Summary

Addressed shortcomings for reusable systems

- Limited data available
- More expensive than expendable hardware
- Heavier than expendable counterpart
- Presented advantages of reusable systems
 - Flight hardware analyzed and inspected
 - Databases developed for future use
 - Expensive hardware reused
- Identified approaches to enhance reusability
 - Reusability should be a primary requirement
 - Components with high failure rates are readily accessible
 - Post-flight inspections minimized

Future Work

- Thesis Statement Developing a methodology that evaluates the efficacy for reuse of space flight hardware is the first step in identifying parameters for reusability.
- The next steps are to:
 - Review parameters for completeness
 - Determine how to quantify parameters
 - Identify potential data sources for reliability, cost, etc



- Reuse must be intentional
- Reuse must not only be a goal, but a requirement beginning in the conceptual phase and implemented throughout the design
- It is not free nor easy, but...
 - Offers potential for significant cost savings
 - Provides opportunity to understand how flight hardware actually performs
 - Allows development of databases for future endeavors