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

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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

(Heald 1995)

Figure 1: Penalties for Reusability

Features for Reuse Implementation

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, producibilty and operability
   - Enables investigation of anomalies
   - An active test program, coupled with actual flight data, enhances the reliability of the hardware
   - Builds engineering confidence

Features for Reuse Implementation

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

Features for Reuse Implementation

4. Easy Access

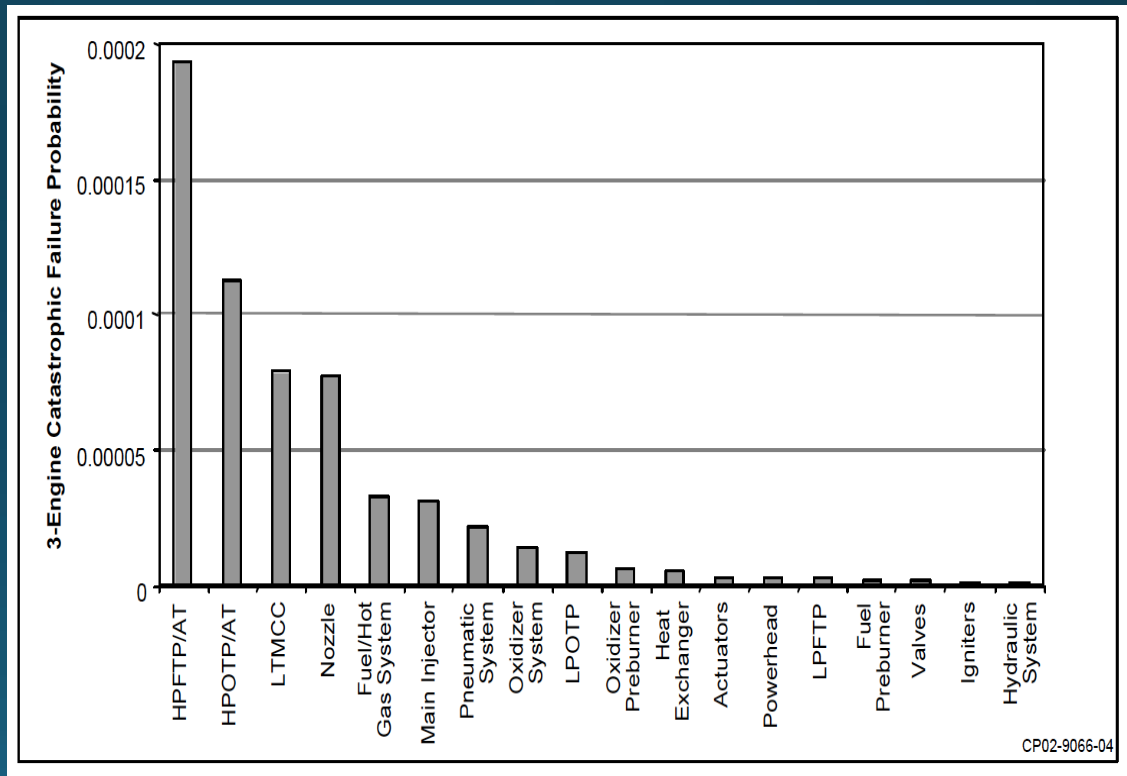
- Components with higher failure rates and require more maintenance should be readily accessible.
- Assembly and disassembly must be simplified to improve turnaround time.
- Complex labor-intensive interfaces such as bolted joints with torque specification and patterns should be replaced with quick connect/disconnect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

Features for Reuse Implementation

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

Features for Reuse Implementation

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

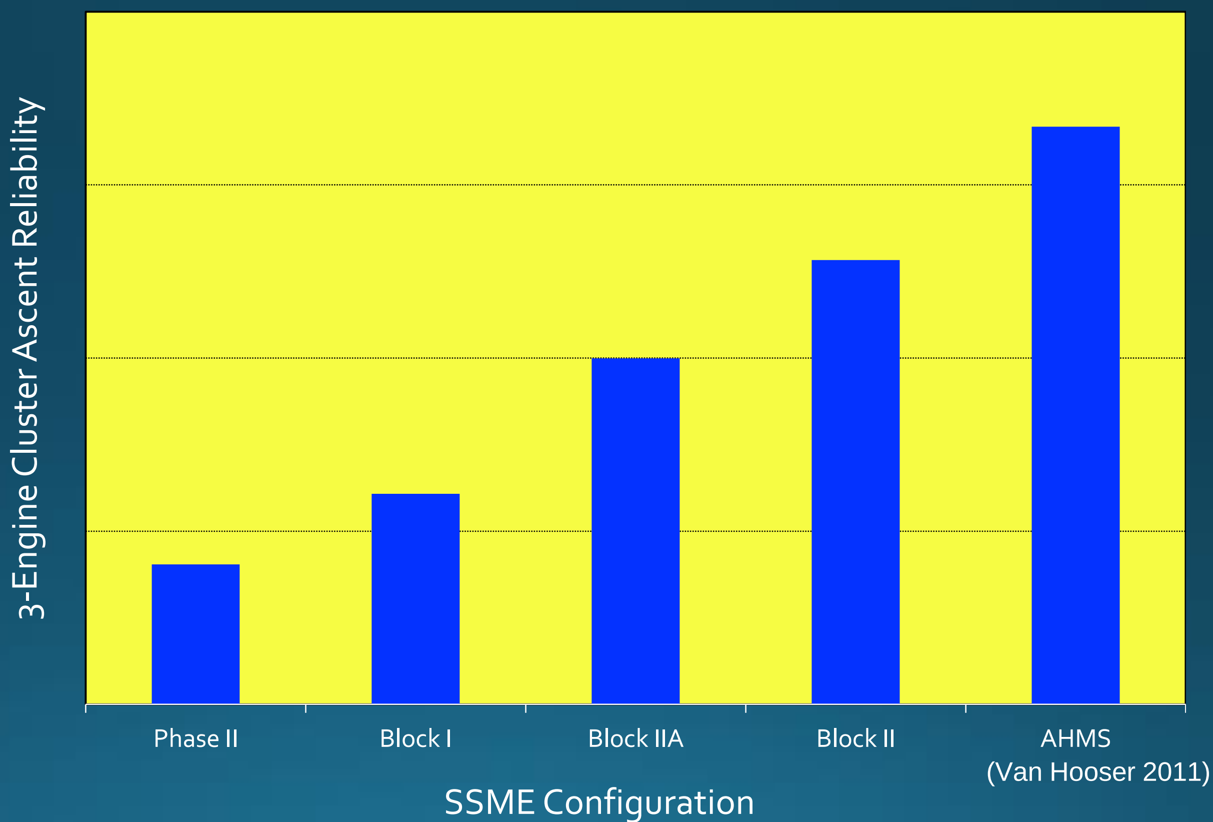
Features for Reuse Implementation

7. Evolutionary vs. Revolutionary Changes

Designs should evolve from existing designs

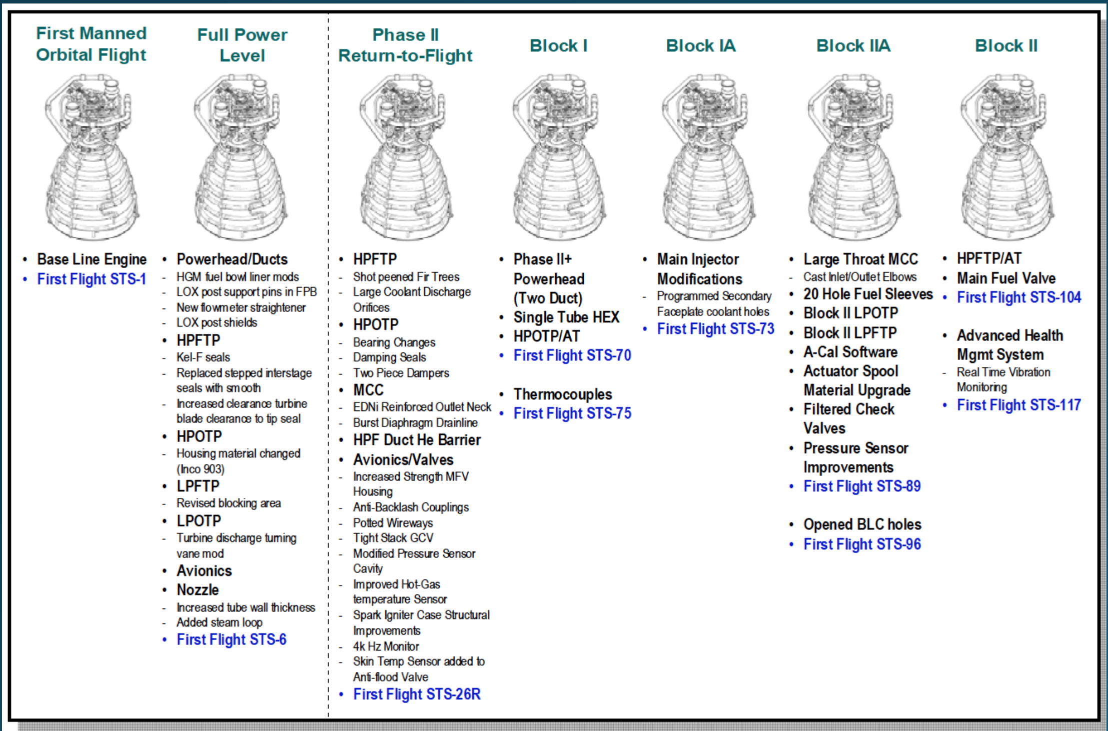
- Limits development unknowns
- Allows incremental changes to improve the design
- Provides opportunity to increase reliability

Figure 3: SSME Reliability Improvements



Features for Reuse Implementation

7. Evolutionary vs. Revolutionary Changes



(Wofford 2010)

Figure 4: History of Major SSME Upgrades

- 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

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

Conclusion

- 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