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

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

Figure 1: Penalties for Reusability

(Heald 1995)
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, 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
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
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

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
Features for Reuse Implementation

7. Evolutionary vs. Revolutionary Changes

- 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

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
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