Professional Development Short Course On:

Launch Vehicle Systems-Reusable

Instructor:

Edward L. Keith

ATI Course Schedule:  http://www.ATIcourses.com/schedule.htm
ATI's Launch Vehicle Systems-Reusable:  http://www.aticourses.com/launch_vehicle_systems_reusable.htm
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Reusable Launch Vehicles
Class Sampler

This is the most advanced Reusable Launch Vehicle class available. The class introduces modeling strategies that provide the capability to evaluate alternative concepts in a much more realistic fashion than has been practiced in the past. New algorithms based on solid science are introduced. This class provides answers as to why past RLV Programs have not met expectations to replace Expendable Launch Vehicles, and shows how to determine if new reusable alternatives will meet expectations.
Classification System Establishment

- The classification system established herein is a consistent continuum
  - Expendable Stages are the most simple type of vehicle, being so simple that they lack a method of recovery
  - Ballistic Reusable Stages are a simple type of vehicle, falling where it naturally would crash, but having survival features to break the fall and remain intact
  - Glide-back Reusable Stages are more complex vehicles, having wings to alter the ballistic trajectory and possibly a more complex landing system
  - Fly-Back is more complex than a Glide-Back having propulsion and propellants to increase the ability to travel greater distance from the glide trajectory and/or the greater ability to maneuver for flexibility in the landing operation
Sneak Preview of Reuse Penalty

Net Mass Fraction $NMF = \text{Dry Mass}/\text{Propellant}$

Comparison of Net Mass Fraction Trends vs. Vehicle Size (LOX/LH$_2$-Vehicles)

Source: Handbook of Cost Engineering (7.0)
Dr. Dietrich Koelle

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RLV Systems Cost More to Develop

Man-Years

Dry Mass (kg)

Winged Orbital Vehicle

Expendable Launch Vehicle

Solid Rocket Motor

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Reusable Launch Vehicle Sampler
Modeling the Impact of Propellant Density

• The Problem – How are propellants of different bulk densities compared?
• Research suggests that the dry mass fraction and propellant mass fraction of a launch vehicle is closely related to the two-thirds root of the Bulk Density

– The two-thirds root rule is conjecture *

\[
SMF_1 = SMF_2 \times \left(\frac{BD_2}{BD_1}\right)^{0.6667}
\]


The dry weight for two rocket stages, differing only in the propellants selected but containing the same mass of propellant, should be expected to be proportional to the ratio of bulk densities of the selected propellants raised to the two-thirds power.
### “Delta Clipper” SSTO Mass Properties

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>Mass (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Ox Tanks</td>
<td>10,613</td>
</tr>
<tr>
<td>Main Fuel Tanks</td>
<td>24,177</td>
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<tr>
<td>Fairings and doors</td>
<td>10,645</td>
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<tr>
<td>Structural shell</td>
<td>17,151</td>
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<tr>
<td>Payload provision</td>
<td>5,230</td>
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<tr>
<td>Thrust Structures</td>
<td>10,569</td>
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<tr>
<td>Thermal Protection</td>
<td>40,587</td>
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<tr>
<td>Aerosurfaces</td>
<td>11,463</td>
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<tr>
<td>nacelles and shields</td>
<td>2,427</td>
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<tr>
<td>Landing gear</td>
<td>13,449</td>
</tr>
<tr>
<td>Actuation (aerosurfaces)</td>
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<tr>
<td>Thermal Control</td>
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<tr>
<td>Aux Power Units</td>
<td>454</td>
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<td>Main Engines</td>
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<tr>
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<tr>
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<tr>
<td>Dry</td>
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<tr>
<td>Payload</td>
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<tr>
<td>Propellant</td>
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<tr>
<td>GLOW</td>
<td>2,149,390</td>
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</tbody>
</table>

**QUESTION**: What if this were expendable?
Choose Fuel/Ox → Payload Size → Mass Property → Engine Model → Performance

Market Model → Cost Model → Schedule Model → Finance Model

Business Model → Results → Best Case? → Retain Best

Increment Payload (+) → Continue? → Output Best Case

Reusable Launch Vehicle Sampler
Don’t Forget Learning Curves

• But Wait, An industrial Engineer looks over the Trade Study and raises an objection
  – The LCC cost analysis left out the “Learning Curve Effect” (f4)
    • The effect is different because more small engine units would be produced
• “Ah-hah,” says the Engineer, “I thought of that.”

• **Correction Factor (f4) = N \( \frac{\ln(P)}{\ln(2)} \)**
  – Where N is the Nth unit produced
  – P is the learning curve factor (Use 0.85 for aerospace)

• LCC using one Big Engine is = $2,845,897,216
• LCC using eight Small Engines is = $2,540,835,492
• “The LCC is lower for the small engine, but I still like the big engine concept” says the Engineer
### Incentive Differences

**Commercial Incentives**
- Higher Incentive to cut costs
- **Minimize Cost**
- **Maximize Profit**

**Aerospace Contractor Incentives**
- Higher Incentive to increase cost
- **Price Insensitive**
- To Increase Profit

**Market Price**

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**Reconfigurable Launch Vehicle Sampler**

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**Sample-9**
The SSTO Challenge

Ballistic Reusable

Winged Orbital Vehicle

Fly-back First Stage

Trajectory Average Isp = 405-s

Dry Mass Fraction *

ELV SSTO LIMIT

BRV SSTO LIMIT

WING SSTO LIMIT

* Excludes Engines

Propellant (Metric Tons)

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Sample-10
Existing Engines vs. Clean Sheet

• What if an existing engine could be used on a RLV?
  – Lower development cost (significant)

DDT&E without new engine

DDT&E with new engine

No Existing Engine

Existing Engine

DDT&E without new engine

Vehicle Size (GLOW)
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