Professional Development Short Course On:

Launch Vehicle Systems-Reusable

Instructor:

Edward L. Keith

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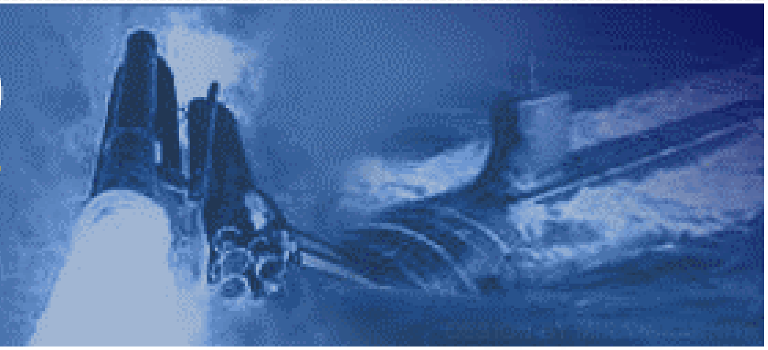

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Reusable Launch Vehicles
Class Sampler

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.

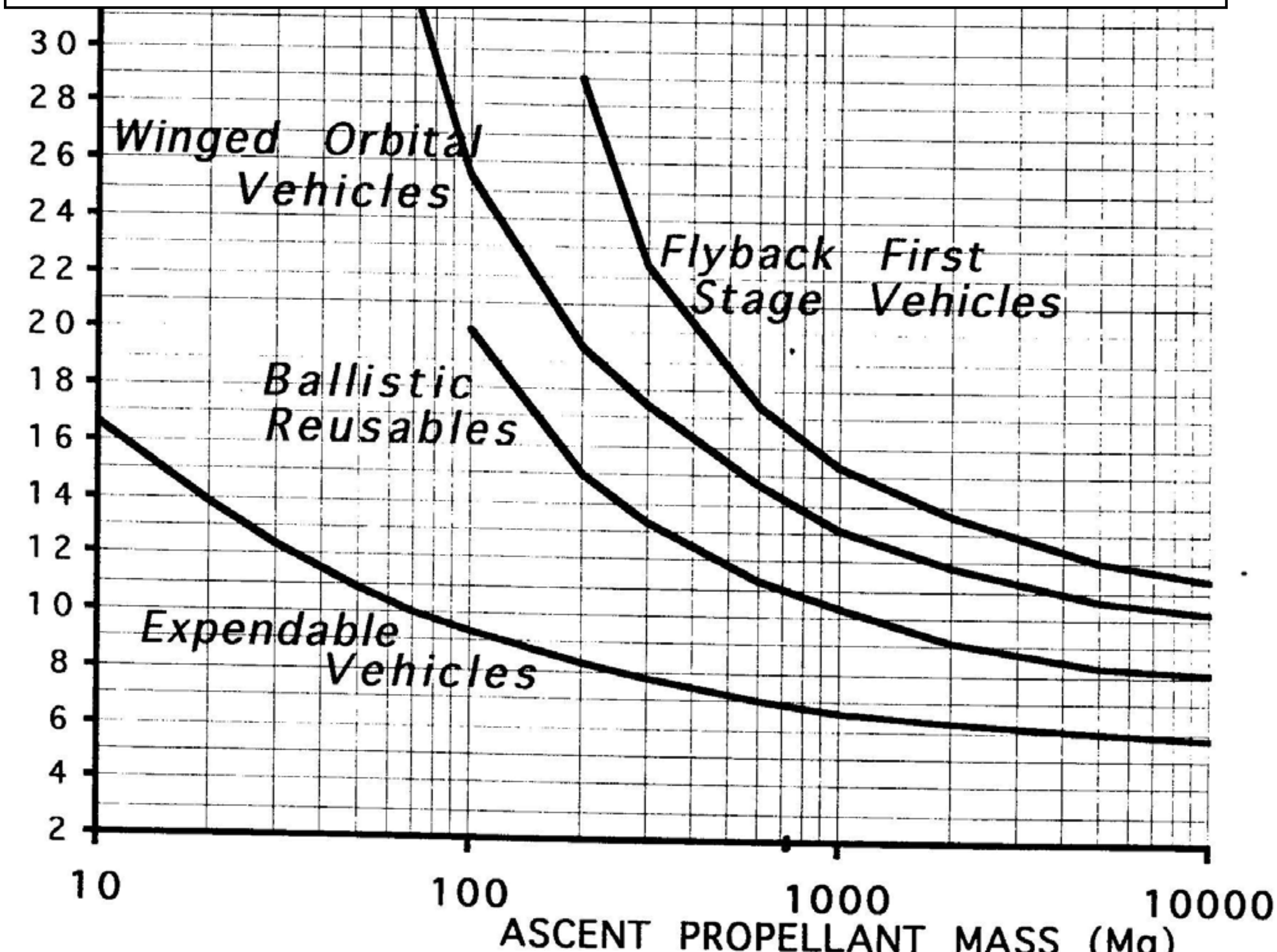
Classification System Establishment

- **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, <u>falling where it naturally would crash</u>, but having survival features to break the fall and remain intact**
  - **Glide-back Reusable Stages are more complex vehicles, <u>having wings</u> to alter the ballistic trajectory and possibly a more complex landing system**
  - **Fly-Back is more complex than a Glide-Back having <u>propulsion and propellants</u> 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 = Dry Mass/Propellant

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



Comparison of Net Mass Fraction Trends vs.Vehicle Size (LOX/LH_2-Vehicles)

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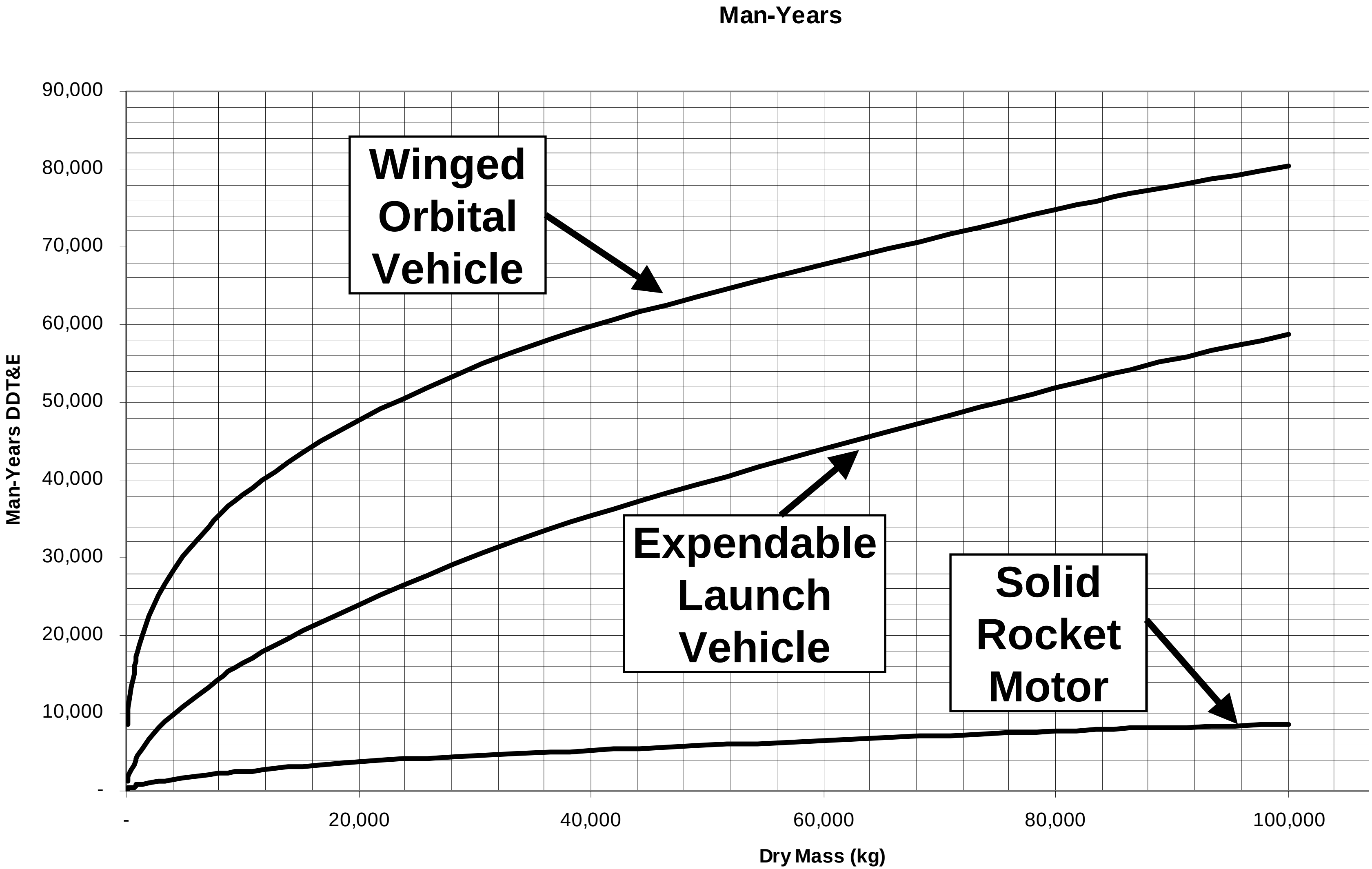
RLV Systems Cost More to Develop



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 *

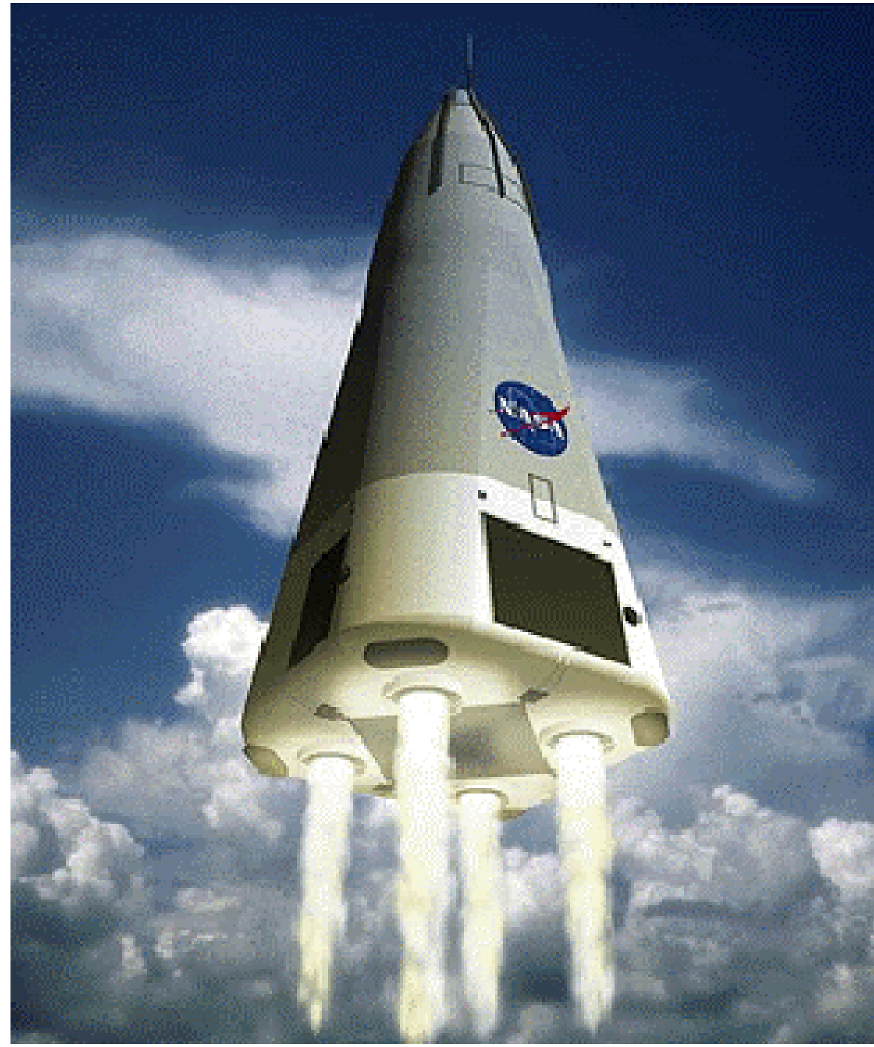
$$SMF_1 = SMF_2 \times (BD_2/BD_1)^{0.6667}$$

* Original observation from Eugene Minick, Mass Properties consultant for the Liquid Fly-Back Booster Project, 1998.

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.

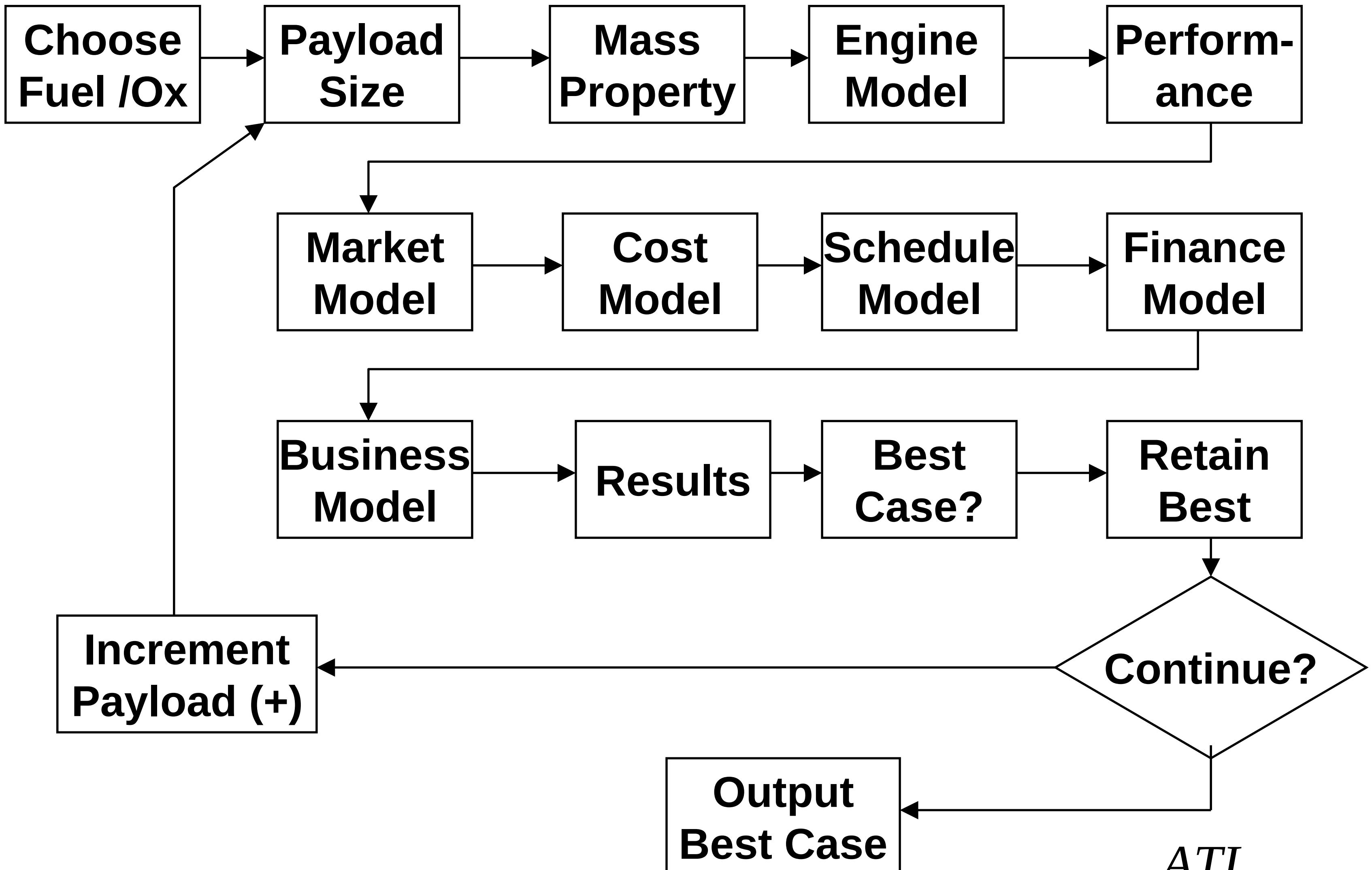
“Delta Clipper” SSTO Mass Properties

ELEMENT	Mass (lbs)
Main Ox Tanks	10,613
Main Fuel Tanks	24,177
Fairings and doors	10,645
Structural shell	17,151
Payload provision	5,230
Thrust Structures	10,569
Thermal Protection	40,587
Aerosurfaces	11,463
nacelles and shields	2,427
Landing gear	13,449
Actuation (aerosurfaces)	3,878
Thermal Control	1,026
Aux Power Units	454
Electrical Power etc.	4,671
Main Engines	41,712
Aux Propulsion	3,507
TVC	1,298
Feed	9,484
Aux Tanks Gas Supply	3,958
Avionics	3,091
Dry	219,390
Payload	20,000
Propellant	1,910,000
GLOW	2,149,390



QUESTION : What if this were expendable?

Sample Integrated Search Model Logic



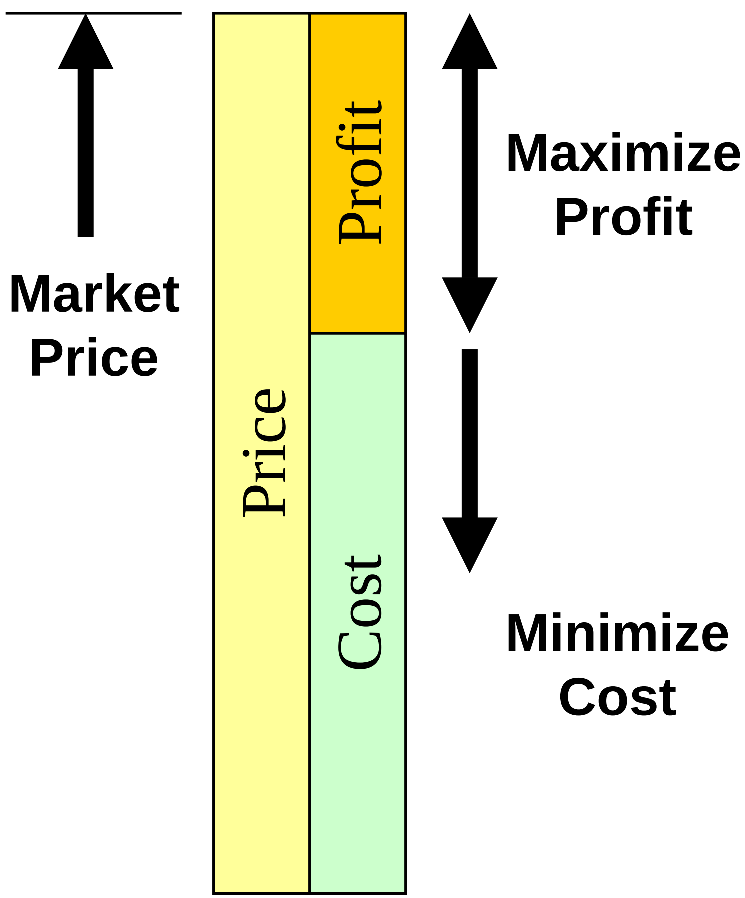
Don’t Forget Learning Curves

- 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) = $N^{(LN(P)/LN(2))}$**
  - 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

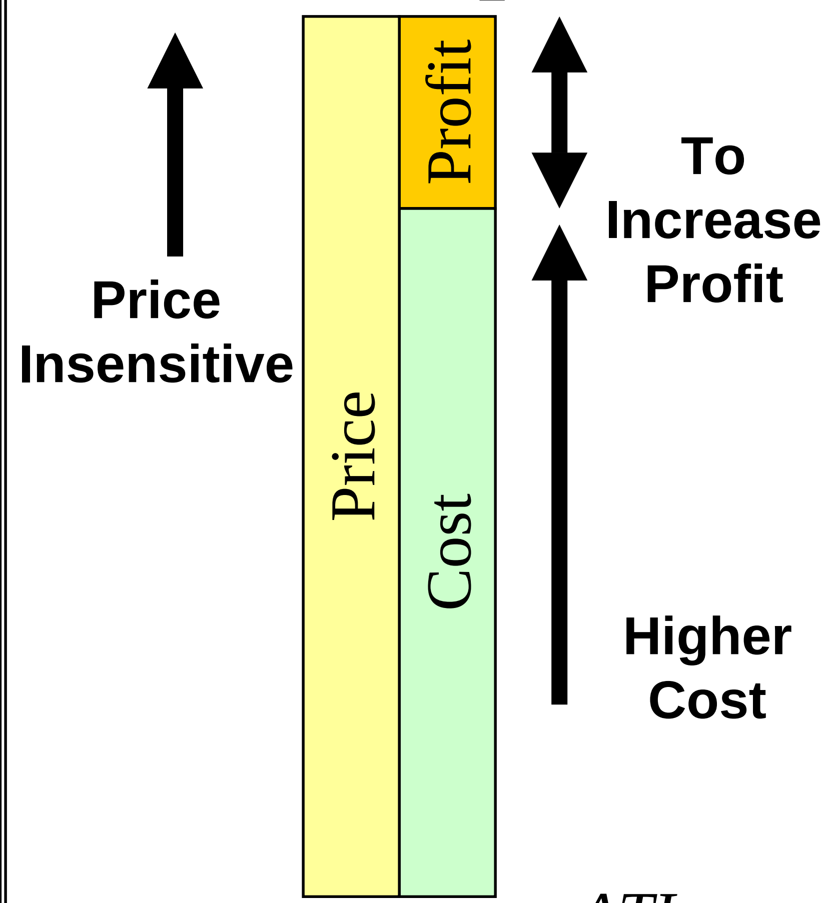
Commercial Incentives

Higher Incentive to cut costs



Aerospace Contractor Incentives

Higher Incentive to increase cost



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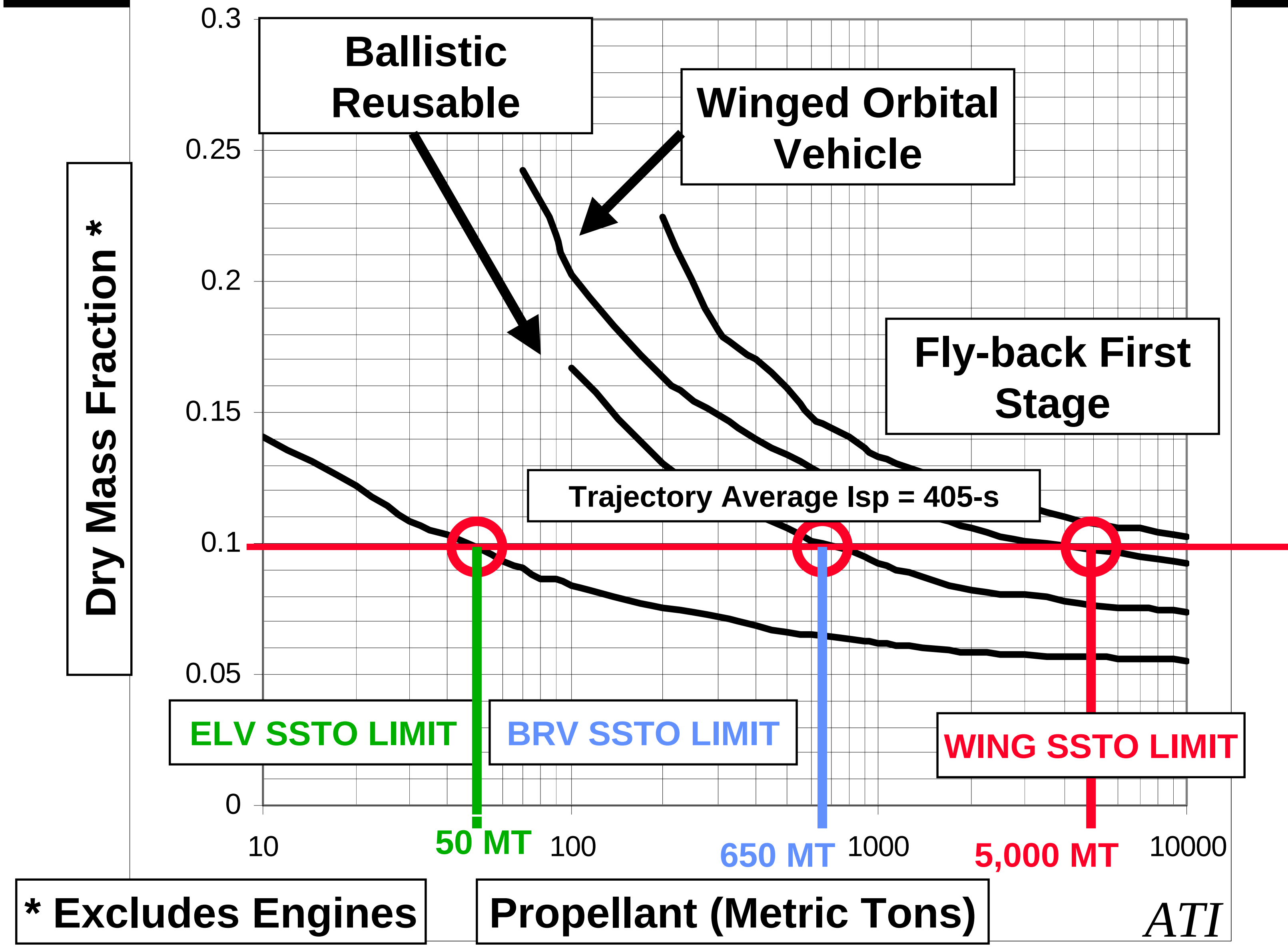
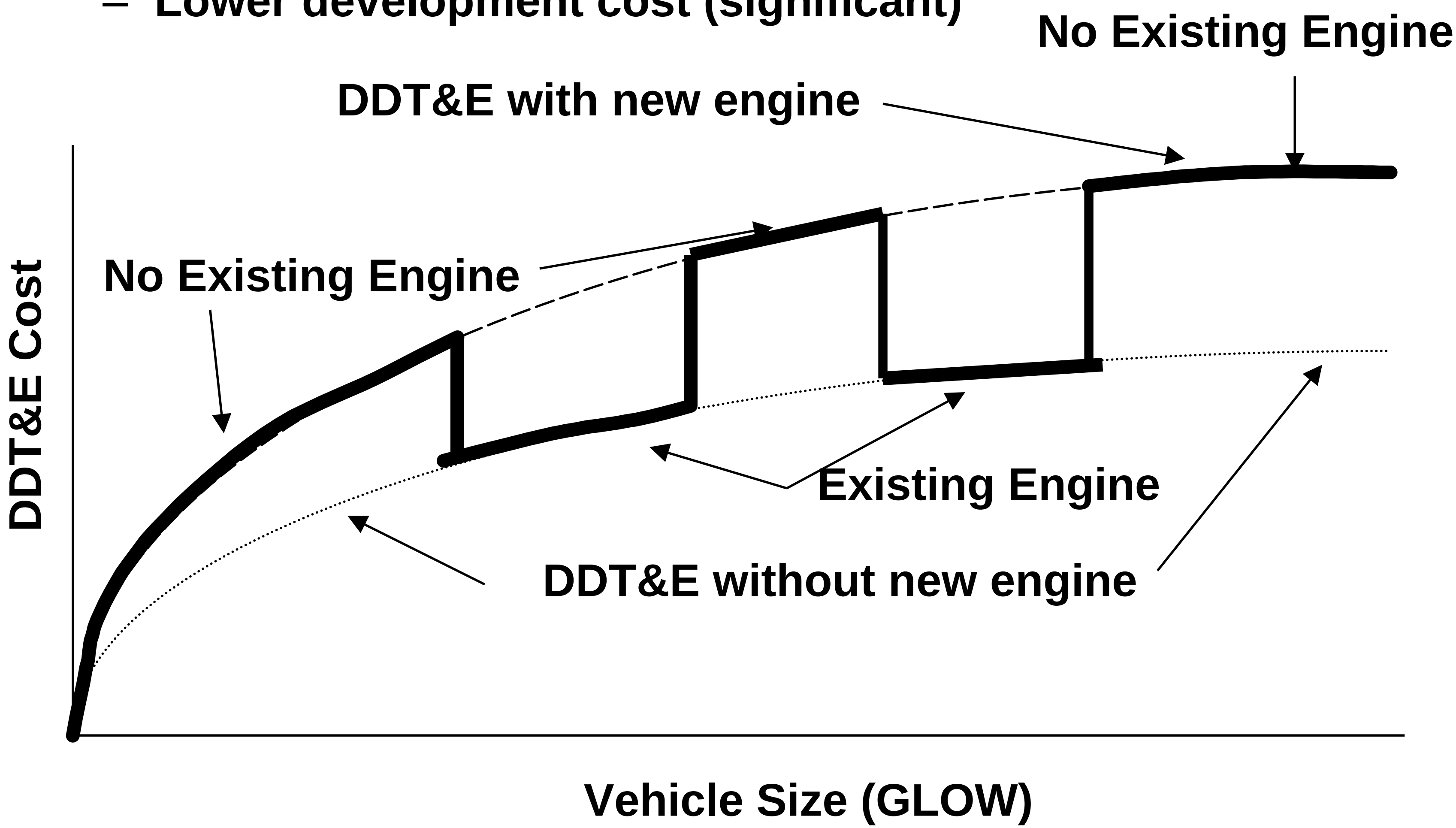
The SSTO Challenge



Existing Engines vs. Clean Sheet

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



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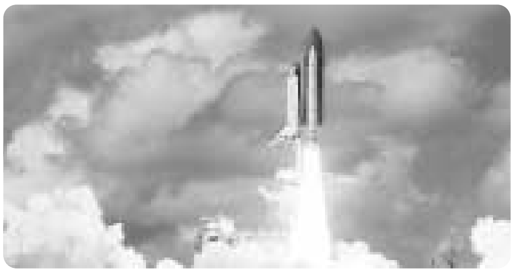

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Our training helps you and your organization remain competitive in this changing world.