Impact of Drag

Drag Loss Example – Slow Burn

m_0 = 80 T, m_p = 60 T, I_{sp} = 240 s, g_0 = 9.81m/s^2, **β = 600** kg/s, C_{D0} = 1.0, $S_r = \pi$ m^2. **D** is maximum at t = 50s.

Determine the **impact** of drag on burnout **parameters**.

Non-drag Values: V_b = 2.30 km/s, h_b = 78.3 km,

h_{50s} = 13.2 km, **ρ_{50s}** = 0.267 kg/m^3, **V_{50s}** = 616 m/s

D_{50s} = 159.1 kN, **m_{50s}** = 50 Tons, **a_{D50s}** = 3.18 m/s^2

a_D = 1.59 m/s^2, **$V_{b\text{-}drag}$**= 2.14 km/s, **$h_{b\text{-}drag}$**= 70.3 km

Drag Loss Example – Fast Burn

$\mathbf{m_0 = 80\ T}$, $m_p = 60$ T, $I_{sp} = 240$ s, $g_0 = 9.81 m/s^2$, $\boldsymbol{\beta} = \mathbf{3000}$ kg/s, $C_{D0} = 1.0$, $S_r = \pi\ m^2$. D is maximum at **t = 15s.**

Determine the **impact** of drag on burnout **parameters**.

Non-drag values: $V_b = 3.07$ km/s, $h_b = 23.4$ km,

$\mathbf{h_{15s}} = 11.5$ km, $\boldsymbol{\rho_{15s}} = 0.337$ kg/m^3, $\mathbf{V_{15s}} = 1799.2$ m/s

$\mathbf{D_{15s}} = 1713.6$ kN, $\mathbf{m_{15s}} = 35$ Tons, $\mathbf{a_{D15s}} = 48.96$ m/s^2

$\mathbf{a_D} = 24.48$ m/s^2, $\mathbf{V_{b\text{-}drag}} = 2.58$ km/s, $\mathbf{h_{b\text{-}drag}} = 18.5$ km

Impact of Burn Rate on Overall Performance

The **results** obtained for drag **bring** out the fact that **drag** loss increases rapidly as we **increase** the burn rate.

On the **other** hand, we have already **seen** that gravity loss reduces **significantly** with increase in burn **rate**.

Therefore, we **realize** that there is **possibility** of a burn rate for which the **both** these losses can be kept **minimum** so that combined loss may **also** be a minimum.

Combined Minimum Loss Example

$\mathbf{m_0 = 80\ T}$, $m_p = 60$ T, $I_{sp} =$ **240 s**, $g_0 = 9.81 m/s^2$, $C_{D0} = 1.0$, $S_r = \pi\ m^2$.

Obtain the variation of combined **energy** loss as a function of **burn** rate and locate the **minima** and determine the corresponding **optimal** burn rate.

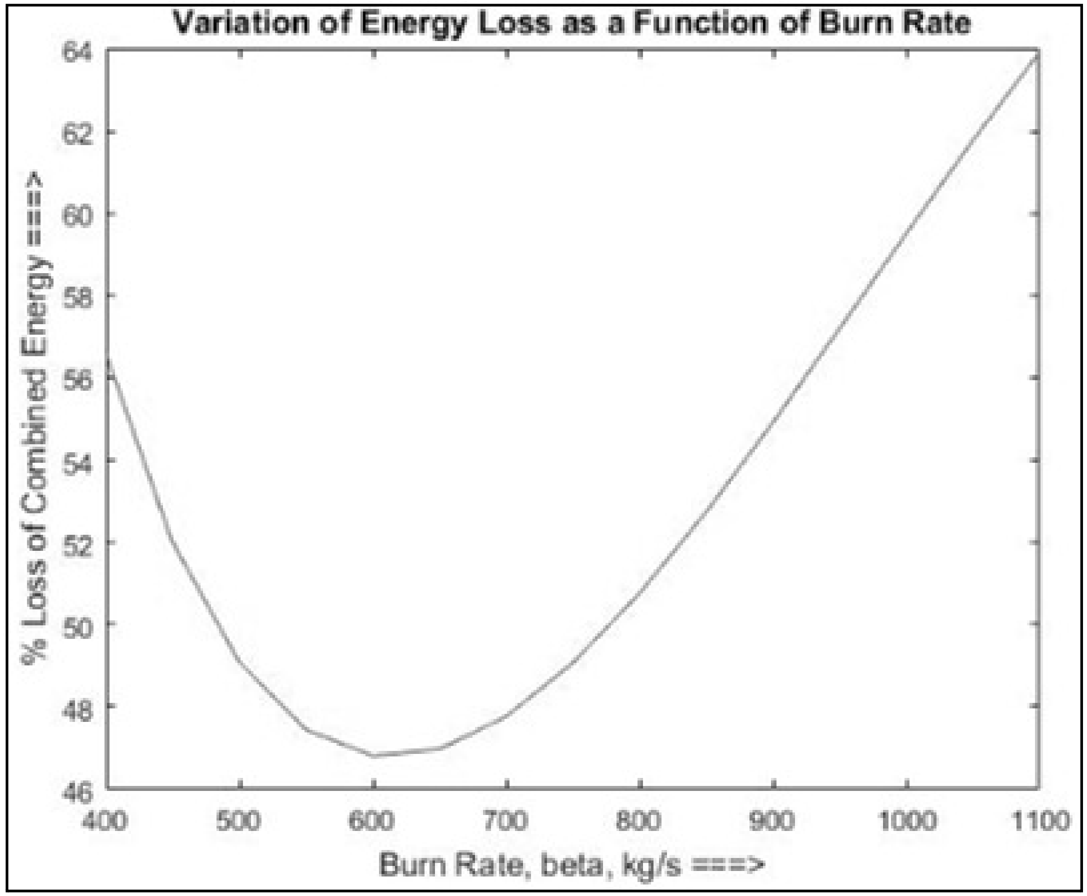
Let us **assume** that drag profile **peak** is at 12 km altitude and **use** β in the range 400 to **1200**.

Combined Minimum Loss Example

An **approximate** solution for this case is **shown** alongside.

We note that the **minima** in this case is close to $\beta = \mathbf{600}$ kg/s.

However, this is only an **approximation** and we need a more rigorous **analysis** to arrive at the **optimal** burn rate.



A Generic Solution for Optimal β

While, a **rigorous** solution for 'β' is generally carried out **towards** end of design, there is a need for a **gross** value at the start of the **design**, in order to assess **performance**.

Such a **value** can be typically obtained by using the **hypothesis** that an optimal '**β**' would lie close to the **trajectory** that has equal gravity and **drag** loss.

This is **based** on the fact that the **variation** of these two effects are **broadly** similar and also that when **gravity** is secondary effect, **drag** is tertiary effect and vice **versa**.

Summary

An **optimal** burn rate exists that **results** in the most efficient **mission** for a given vehicle from the **point** of view of minimizing the **combined** gravity and drag loss.