Homework 1

- Space Shuttle has the following mass fraction characteristics

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Weight (lb)
 Gross lift-off . . . . . . . .  4,500,000
 External Tank (full) . . . .  1,655,600
 External Tank (Inert) . . . .     66,000
 SRBs (2) each at launch . . . 1,292,000
 SRB inert weight, each . . .  . 192,000
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- ***1) Calculate the actual propellant mass fraction as the shuttle sits on the pad***

$$P_{mf} = \frac{M_{propellant}}{M_{"dry"} + M_{payload}}$$

$$P_{mf} = \frac{M_{initial}}{M_{final}} - 1$$

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Homework 1 (cont'd)

- Assume that Shuttle is being launched on a Mission to the International Space Station (ISS)

- ISS orbit altitude is approximately 375 km above Mean sea level (MSL), assume that Shuttle Pad 41A altitude approximately Sea level, *Latitude is 28.5 deg. , ISS Orbit Inclination is 51.6 deg.*

- Assume that the Earth is a perfect sphere with a radius of 6371 km

$$\mu_{\oplus} = M_{\oplus} \cdot G = 3.9860044 \times 10^{5} \frac{km^3}{sec^2}$$

- Calculate

2) The required Orbital Velocity
3) The "Boost Velocity" of the Earth at the Pad 41A launch site (along direction of inclination)
4) Equivalent "Delta V" required to lift the shuttle to altitude
5) Total "Delta V" required to reach the ISS orbit

Homework 1 (cont'd)

- The ***2*** SRB's each burn for approximately 123 seconds and produce 2,650,000 lbf thrust at sea level

- The ***3*** SSME engines each burn for ~509.5 seconds and each produces 454,000 lbf thrust at sea level

- ***Each*** of the SSME's consume 1040 lbm/sec of propellant

6) Calculate the average specific impulses of the SRB's, the SSME's, and the Effective specific impulse of the Shuttle Launch System as a whole during the First 123 seconds of flight (ignore altitude effects)

Hint: $$I_{sp} = \frac{\int_0^{T_{burn}} F_{thrust} \cdot dt}{g_0 \int_0^{T_{burn}} \dot{m}_{propellant} \cdot dt} = \frac{(\mathrm{I}mpulse)_{total}}{g_0 M_{propellant}}$$

Homework 1 (cont'd)

7) Based on the calculated "Delta V" requirements for the mission, what would be the required propellant mass fraction For the space shuttle to reach orbit in a single stage assuming the mean launch specific impulse?

-- base this calculation on the mean I_{sp} for the system during the first 123 seconds after launch

8) How does the shuttle manage to reach orbit? …. ?

Homework 1 (cont'd)

…. Next evaluate estimate launch conditions by breaking calculation into two "stages" .. That is

i) Stage 1 … first 123 seconds … SRB's and SSME's burning
ii) Stage 2 … after SRB's jettisoned .. Only SSME's burning

"stage 1"

"stage 2":

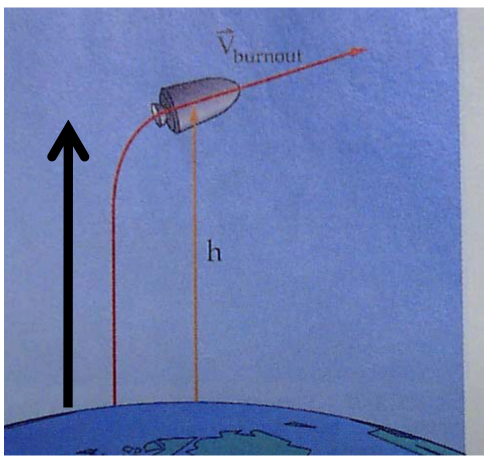
$$\Delta V_{total} = \Delta V_{stage1} + \Delta V_{stage2} + \Delta V_{stage3} \ldots = \sum_{i=1}^{\#\,of stages} \Delta V_{stage\_i}$$

Homework 1 (cont'd)

i) Stage 1 … first 123 seconds … SRB's and SSME's burning

-- Assume shuttle flys ~ "vertically" during Stage 1 flight. …

"stage 1"
Flight is vertical



9) Calculate "Available Delta V" for "stage 1" Based On Mean I_{sp}, and P_{mf} (ignore altitude effects)

-- Include "gravity losses" and assume an 8% drag loss in the available propulsive "Delta V" … assume $g(t) \sim g_0 = 9.8067 m/sec^2$

$$(\Delta V)_{available} = g_0 \cdot I_{sp} \cdot \ln\left(\frac{M_{initial}}{M_{final}}\right) - (\Delta V)_{\substack{gravity\\loss}} - (\Delta V)_{drag}$$

$$(\Delta V)_{drag} \approx \mathbf{0.08} \times g_0 \cdot I_{sp} \cdot \ln\left(\frac{M_{initial}}{M_{final}}\right)$$

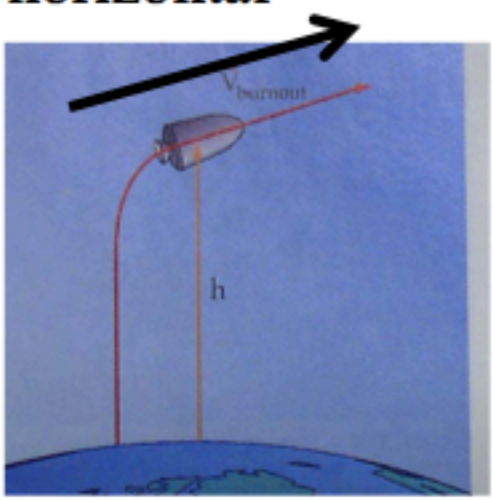
Homework 1 (cont'd)

... Break Calculation into two "stages" .. That is

ii) Stage 2 ... flight time from 123 seconds to SSME burnout

-- Assume shuttle flys ~ "horizontally" during Stage 2 flight. ...

"stage 2" flight is horizontal



-- 10) Calculate "Available Delta V" Based On SSME I_{sp}, and remaining P_{mf} after the SRB's Have been Jettisoned

-- Assume no drag losses for stage 2 burn

-- 11) Compute total available delta V .. Compare to mission requirements