DEPARTMENT OF AEROSPACE ENGINEERING

Indian Insitute of Technology Kanpur

Rocket Propulsion (Code: AE441A)

Instructor: Sathesh Mariappan

Assignment due: 3 September 2021

Course assignment Maximum Marks: 10

1. (a) Plot the rocket trajectory (horizontal (x) vs. vertical (h) distance), rocket speed (u vs. t), rocket angle (θ vs. t) and rocket height (h vs. t) until the burn out time ($t = t_b$). Also tabulate the burnout height (h_b), burnout speed (u_b), and angle of rocket at burnout (θ_b). The rocket is fired from the ground (at $t = 0 : x, h = 0$) at an angle of 1 degree from the vertical ($\theta = 1$ degree) with a non-zero initial vertical velocity 30 m/s. Given: constant equivalent exhaust velocity $u_{eq} = 3048$ m/s, initial rocket mass (M_0) = 15000 kg, propellant mass (M_p) = 12000 kg, burnout time (t_b) = 100 s, constant acceleration due to gravity (g_0) = 9.81 m/s^2, neglect drag ($D = 0$), assume constant mass burning rate ($\dot{m}$). Compute the results (overlay the plots for the cases a-d and tabulate other results) if all other parameters are as given above and:

   (b) Only acceleration due to gravity (g) varies (and $D = 0$): with height (h): $g = g_0 \left[R_e/(R_e + h)\right]^2$, where, R_e is the earth's radius = 6,400 km.

   (c) Only drag (D) varies (and $g = g_0$): with ambient gas density (ρ) and rocket velocity (u): $D = C_D(1/2)\rho u^2 A_f$, where, C_D is the coefficient of drag = 0.1 (assumed constant), A_f is the frontal cross-sectional area of the rocket = 1 m^2. $\rho(h) = 1.2exp\left(-2.9 \times 10^{-5} h^{1.15}\right)$ kg/m^3, h is in m.

   (d) Both g and D varies: as given in (b) and (c), respectively. Try with different time steps ($\Delta t = 0.1$ s, 0.01 s...etc).

   (e) Realistic condition: C_D varies with Mach number according to the plot shown in figure 1. Further, formula to calculate atmospheric temperature with altitude is given in figure 2. This is used to calculate Mach number of the rocket from its velocity.

[10]

Student's name:

Question 1 continues on the next page...

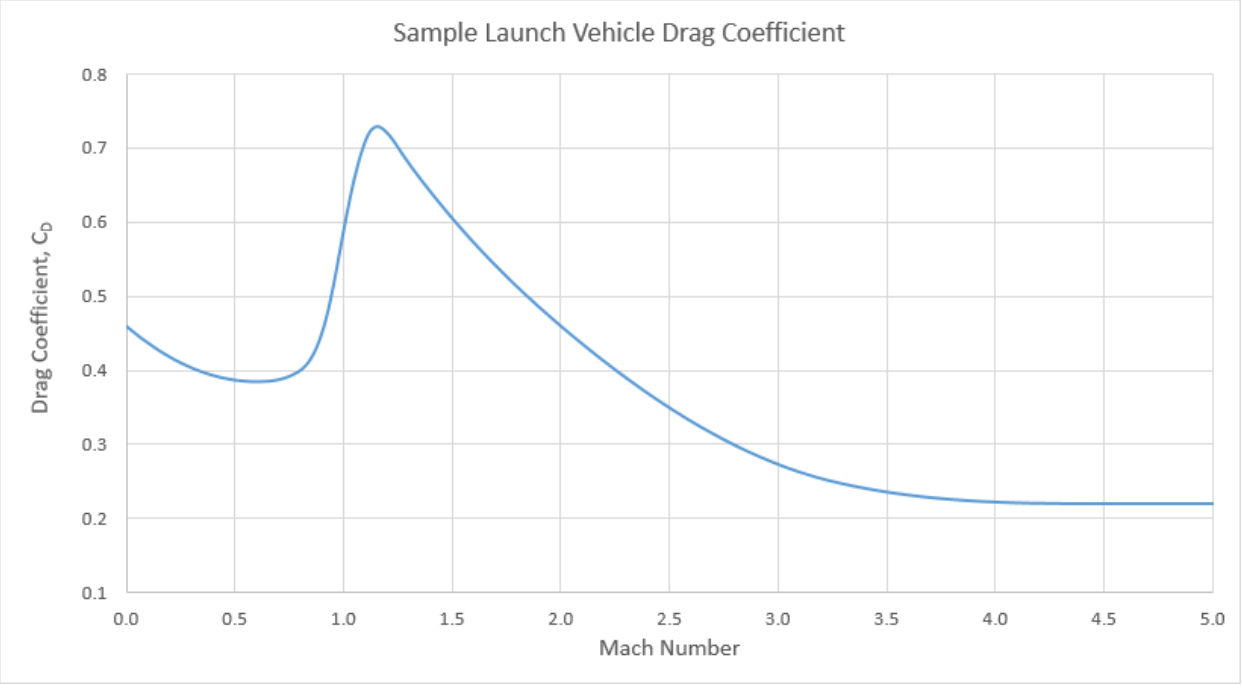

Figure 1: Variation of drag coefficient C_D with flight Mach number M for a typical launch vehicle. Source: http://www.braeunig.us/space/aerodyn_wip.htm

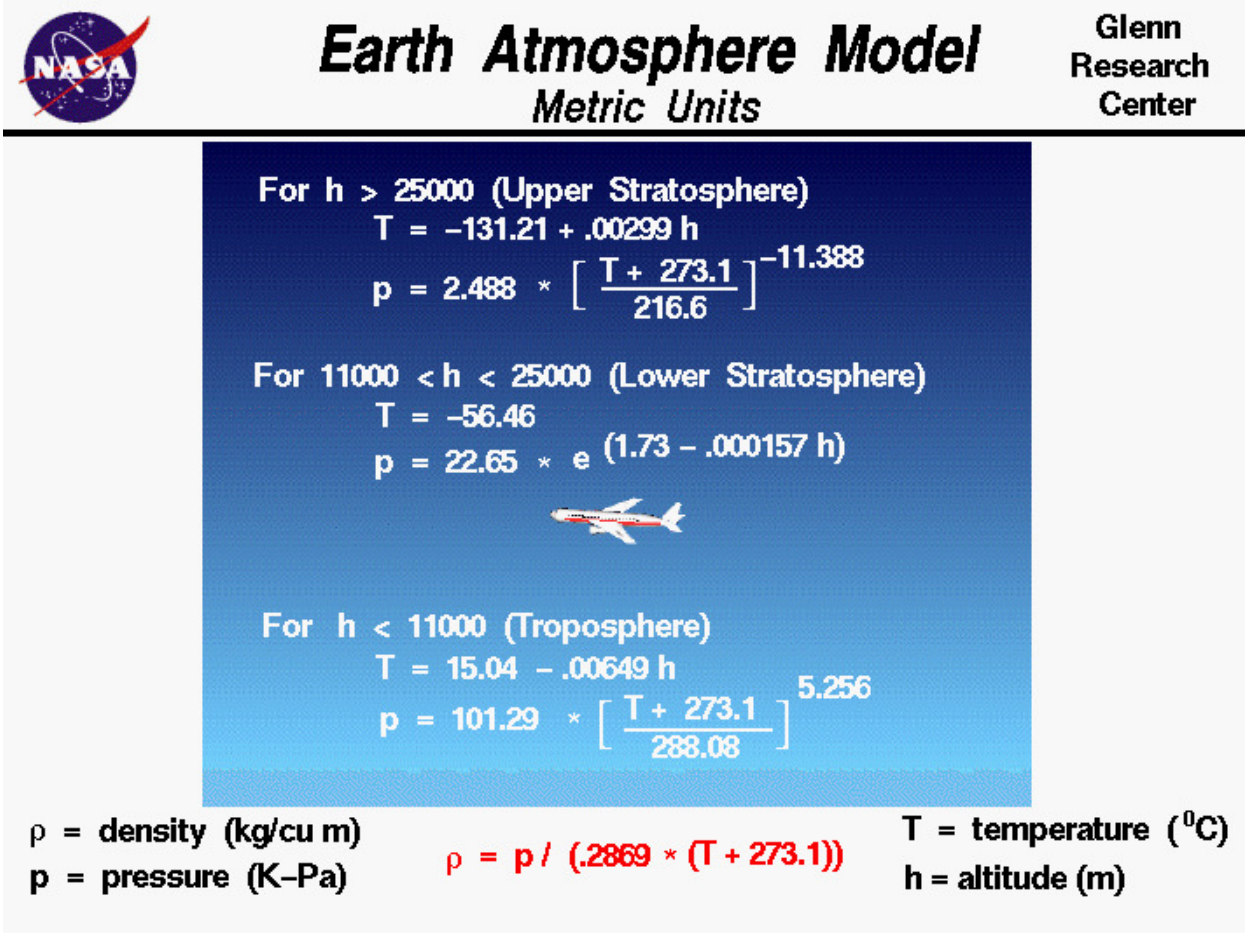

Figure 2: Formula to calculate atmospheric temperature at various altitudes. Source: https://www.grc.nasa.gov/www/k-12/airplane/atmosmet.html