## ENAE 791 PROBLEM SET 2 - SPRING, 2014

DUE 3/13/14
(1) In his novel The Moon is a Harsh Mistress, Robert Heinlein tells the story of a lunar colony fighting for independence from Earth by, among other things, throwing containers of rocks at targets on the Earth's surface. The story compares the impact of these projectiles to the explosive potential of a nuclear bomb.
(a) Assume the projectile encounters Earth's atmosphere at an entry flight path angle of $-70^{\circ}$ and velocity of $11 \mathrm{~km} / \mathrm{sec}$. The projectile is spherical $\left(c_{D}=1\right)$ with a mass of $10,000 \mathrm{~kg}$ and a density of $3000 \mathrm{~kg} / \mathrm{m}^{3}$. Using the second ballistic entry approximation (altitude as the independent parameter, rather than atmospheric density),
(i) Plot velocity vs. altitude
(ii) Plot deceleration vs. altitude
(iii) Calculate the impact velocity of the projectile
(iv) If a kg of TNT has an explosive energy of 4184 kJ , what is the "explosive potential" of this projectile? Does it compare to a nuclear bomb ( $\sim 100$ kilotons of TNT)?
(b) Maintaining the spherical shape and density from above, what projectile mass would result in ground impact at the point of maximum deceleration?
(2) Write a computer routine (program, MatLab script, or Excel spreadsheet, whatever works for you) to numerically integrate the planar state equations for atmospheric entry derived in class. Model the entry of an Apollo spacecraft $\left(1 / \mathrm{d}=0.3, \beta=350 \mathrm{~kg} / \mathrm{m}^{3}\right)$ in an orbital entry ( $\gamma_{e}=-3^{\circ}, v_{e}=7700 \mathrm{~m} / \mathrm{sec}$ ) with the lift vector upwards.
(a) Plot velocity vs. altitude
(b) Plot deceleration vs. altitude
(c) Plot downrange distance vs. altitude
(d) Plot velocity vs. deceleration

