Department of Aeronautics and Astronautics

Field Exam in Space Propulsion

January 2009

Every student should attempt to solve all (4) problems. If your oral presentation takes more than approximately ten minutes for a particular problem, you will be asked to try a different one. You will be allowed to work on unfinished questions if time permits.

Problem 1

Assume the International Space Station receives an electric propulsion engine that will fire continuously to compensate for high-altitude atmospheric drag over the lifetime of the station (say, 15 years). Calculate the specific impulse that would minimize the mission cost. Assume the following:

- Cost of propellant (in orbit) = $5,000 per kg
- Cost of propulsion system = $50,000 per kg
- Engine efficiency = 0.7
- Propulsion system specific mass = 20 kg/kW

Problem 2

In a certain Xenon plasma thruster (molecular mass=131 g/mol), the electron density and temperature near the ceramic wall are known from measurements to be $n_e = 10^{18}$ m^{-3} and $T_e = 20$ eV. Estimate the heat load to the wall (power deposited per unit area). State the assumptions made and explain the physical effects in the near-wall plasma that are involved.

Problem 3

In designing the cooling passages for liquid rockets, it is suggested that promoting roughness on their internal wall is an effective way to increase the thermal contact with the liquid. But at the same time this raises the friction coefficient, which tends to increase the pressure drop in the passages.

The amount of coolant available (usually the fuel) is fixed, and so is the local heat flux to a first approximation, since the gas stagnation temperature is so much more than the outer wall temperature. In addition, if the coolant can decompose chemically, its temperature at each section along the passage should be maintained fixed, such as to have a fixed (near maximum) total temperature rise in the passage.

Calculate the effect of an increase by a factor (say f) in the friction coefficient due to induced roughness, on the total pressure drop in the cooling passages.

Assumptions:

- An idealized cooling passage geometry, i.e., circular cross-section and constant diameter, with a fixed length.
- The Reynolds analogy holds in the presence of roughness.
- One can accommodate variations in cooling passage diameter and liquid flow velocity, as required to maintain fixed flow rate and local heat flux.
- These changes do not by themselves affect the friction coefficient, because the Reynolds number is very high.

Based on your results, is roughening a recommended procedure?

Problem 4

A small space vehicle is designed for a mission that requires escape from the earth gravitational influence. The spacecraft is to be delivered as a secondary payload on a GEO-bound rocket. The launch operators are willing to deliver the small satellite in either a GTO orbit (perigee at 350 km) or in GEO.

What option would provide the largest propellant mass savings if using:

(a) Chemical propulsion
(b) Electric propulsion

Clearly state your assumptions and be as quantitative as possible in your selection.

For the earth: $\mu = GM_e$ = 398601 km^{3}s^{-2}, R_E = 6378 km