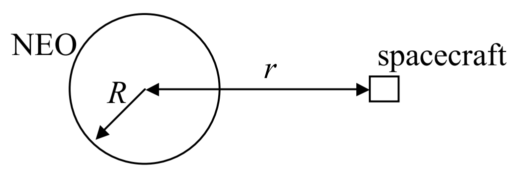
Department of Aeronautics and Astronautics
Field Exam on Space Propulsion
January 2010

*Choose **TWO** of the following three problems. Manage your time carefully. Do not spend too much time working on algebraic steps. It is important to uncover the physical concepts and logical steps to reach a solution. Reflect on what is being asked before rushing into the mathematics of the problem.*

Problem 1

The impact of a Near Earth Object (NEO) on the earth has the potential of producing catastrophic effects. Even though the probability of such event is very low, nations are considering strategies to deflect NEOs. A proposed approach consists of gravitationally pulling an NEO with a spacecraft flying in close proximity to the asteroid, thus producing a velocity change ΔV_{NEO} that would move the orbital path away from its collision course. In this problem you will analyze the gravitational deflection of a spherically shaped NEO of mass M and radius R through a spacecraft (payload/structure + propulsion/power system + propellant) *hovering* during a time τ at a constant distance r from the NEO center as shown below. Assume the vector aligned with r is always parallel to the NEO orbital velocity vector.



(a) Propose a propulsion configuration. What is the instantaneous thrust required? Assumptions: perfectly collimated engine exhaust, constant Isp and a specific mass (per unit power) for the propulsion/power system of α.
(b) Compute the gravitationally imparted ΔV_{NEO}.
(c) Comment on the tradeoffs that would lead to the selection of the separation distance, r.
(d) Comment on what type of propulsion system would be required for such a mission.

Problem 2

It has been proposed that an electrospray thruster array could operate in the pure ionic regime in a configuration where the extraction grids are replaced by a plasma sheath. The hypothesis is that the potential drop in the sheath would produce an electric field able to extract ions from the surface of an ionic liquid.

(a) Estimate the magnitude of the electric field in terms of the plasma temperature and plasma density.
(b) Comment on the feasibility/practicality of this approach.

Problem 3

SCALING OF A HALL THRUSTER FOR HIGH POWER

Hall thrusters are well developed and understood for power ranges around 1-10 kW. When one considers the use of a Hall thruster for very high powers, say of the order of 1MW, several issues need to be investigated:

(a) Changes to the degree of collisionality (λ_{mfp}/L, where λ_{mfp} means the electron mean-free-path and L is some characteristic length, like the diameter).
(b) Changes to the wall temperature and to the wall heat flux that may require active cooling.
(c) Changes to the engine mass/power ratio (the α_{engine} parameter for the engine alone).
(d) Other changes, like the magnetic field strength and the ratio of gyro radius to diameter.

These factors are fairly much determined by the designer's choice of one scaling parameter, and we will here take that to be the exponent n in the mass dependence on power, i.e., in the relationship $M_{engine} \propto P^n$.

Assume:

- The voltage, specific impulse and efficiency will vary only weakly with power level P.
- The fraction of the lost power $(1-\eta)P$ that is deposited on the wall is also nearly invariant.
- The outer surfaces of the engine are cooled by direct radiation to space, and other heat disposal paths are negligible.
- The engine proportions are preserved, so that engines of different powers are photographic reproductions of each other.
- The same gas is used throughout.

With these assumptions, derive the exponents in the power dependence of the quantities λ_{mfp}/L, T_w, q_w, n_e and α_{engine}. For example, what is m in the relationship $\frac{\lambda_{mfp}}{L} \propto P^m$?

Select the parameter n needed to leave each of these quantities in turn invariant with power, and build a table showing how the others vary in that case. Based on this table, make a tentative recommendation on the best choice of n, and explain your reasoning