MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Aeronautics and Astronautics

Field Exam in Space Propulsion
January - 2012

- Read carefully each problem before writing your solution. There are **TWO** problems in this exam.
- Make sure to state and be consistent with the problem assumptions.
- Identify clearly your line of thought in your solutions.
- Manage your time with care.

Problem #1

There is renewed interest in the concept of air-launched rockets for payload delivery to Low Earth Orbit (LEO). The simplest implementation is the one exemplified by the Pegasus launcher: the rocket is carried by a jet transport plane to some altitude of the order of 10,000 m. and released. After a few seconds for separation and stabilization, the first stage rocket engine fires and the vehicle follows a shallow ascent trajectory.

- Discuss the advantages and limitations of this approach, considering as many effects as possible.
- Provide first-order estimates of gains or losses.

Problem #2

Electrospray thruster operation in the pure ionic regime is possible with ionic liquids (room temperature molten salts). The advantages of this operating mode are high Isp, high efficiency and thruster compactness. However, the general understanding of this mode is not as developed as in the colloid (droplet) regime. A useful theory should, at the very minimum, be able to predict the size of the region at the electrified meniscus from which ions are field evaporated r^* and the current I^* that could be obtained from such a meniscus.

Propose an approach to estimate both r^* and I^* and calculate their numerical values. Is this consistent with the observed current levels (>1 μA/emitter) in porous metal electrospray thrusters?

Assumptions:

1. Ion emission relies on field evaporation $j = \sigma \frac{kT}{h} \exp\left[-\frac{1}{kT}\left(G_0 - \sqrt{\frac{e^3 E}{4\pi\varepsilon_0}} \right) \right]$, which is not appreciable until the electric field reaches a critical value E^*.
2. The meniscus surface charge σ at the emission region is far from being fully relaxed, such that the non-zero resistivity of the liquid controls charge transport.
3. As usual, the mechanical balance at the liquid-vacuum interface is established by electric pressure $\frac{1}{2}\varepsilon_0 E^2$ and surface tension $\gamma\kappa$ forces, where κ is the liquid surface curvature.

Properties of the ionic liquid EMI-BF_4 @ $T = 300$ K:

Electric conductivity	$K = 1.3$ Si/m
Dielectric constant	$\varepsilon = 10$
Density	$\rho = 1240$ kg/m^3
Viscosity	$\mu = 0.034$ Pa.s
Surface tension	$\gamma = 0.052$ N/m
Activation energy	$G_0 = 1.5$ eV

Physical constants:

Boltzmann	$k = 1.38\times10^{-23}$ J/K
Planck	$h = 6.626\times10^{-34}$ J.s
Permittivity of vacuum	$\varepsilon_0 = 8.854\times10^{-12}$ F/m
Elementary charge	$e = 1.6\times10^{-19}$ C