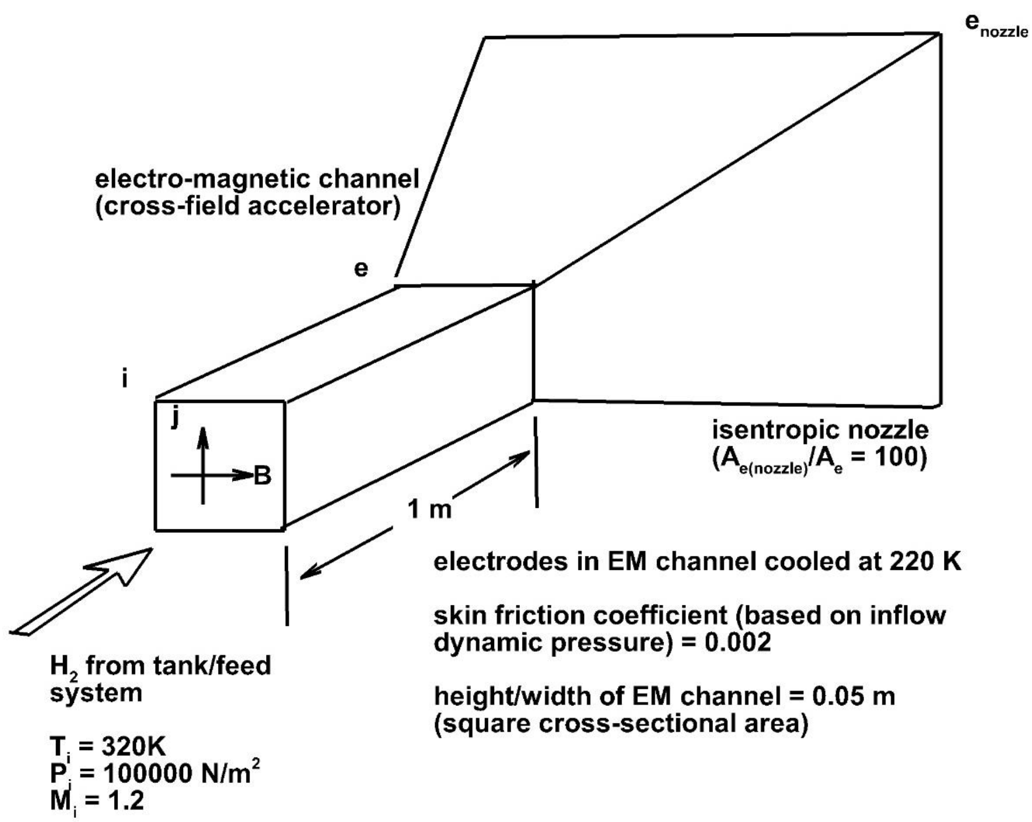
Final Project AE 5535 **Spring 2021** **Assigned: April 16, 2021**

Due: LDOC

Consider a space-based crossed-field accelerator with a downstream expanding nozzle as shown in the sketch below:



Description of accelerator:

Hydrogen (H_2), appropriately seeded to significantly increase its electric conductivity, enters a constant cross-sectional area Electro-magnetic (EM) channel at a Mach number of 1.2, static pressure = 100 kPa, and static temperature = 320K. The channel has crossed electric and magnetic fields in order to accelerate the propellant. Although the electrodes would be discrete in reality, assume a continuous distribution of electrode for preliminary design purposes. It is desired to keep the load factor (η) constant along the length, with constant applied magnetic field strength as well, such that the electric field strength will by necessity vary continually along the length of the channel. Assume that the wall temperature in the EM channel is kept at 220K. Skin friction coefficient (based on the inflow dynamic pressure) is 0.002. The constant area EM channel is a square duct with height = width = 0.05 m and is 1 meter long. Downstream of the EM channel, the flow enters an expanding nozzle. Nozzle expansion ratio (in terms of cross-sectional area) is 100. Assume that the flow in the nozzle is isentropic. Use the EM Lorentz force quasi-one-dimensional model developed in class for this preliminary examination.

Vehicle mission and mass properties:

This accelerator is required to provide a ΔV (absolute change in velocity) of 10000 m/s for a rocket in the absence of atmospheric drag and gravity fields. Ambient pressure in space is 0 atmospheres (no kidding).

The overall mass of the rocket prior to firing of the accelerator is m_0.

$$m_0 = m_L + m_p + m_e$$

m_L = payload mass = 500 kg

m_p = propellant mass

m_e = mass of engine system and supporting structure

The mass of the engine system and supporting structure depends on the strength of the magnets used in the accelerator (B), the degree of ionization of the plasma σ_0 (more ionization requires more massive ionizer), and the load factor associated with the crossed-field accelerator η (smaller η requires more current, heavier wiring circuits, etc.)

Specifically, the mass properties for the engine system and supporting structures are given by the following dependency function:

$$m_e = (1000kg)1.2^{(N_B-1)}1.2^{(N_\sigma-1)}2^{(N_\eta-1)}$$

$$N_B = \frac{B-0.6}{0.2}$$

$$N_\sigma = \frac{\sigma-100}{100}$$

$$N_\eta = \frac{1-\eta}{0.1}$$

Objective:

Determine the set of magnetic field strength, conductivity, and load factor (set of three variables) that minimizes the overall initial mass of the rocket (prior to firing). Search for this minimum mass case over a range of 200 to 600 Ohm/meter for the conductivity using an increment of 100 Ohms/meter. Similarly, examine a range of 0.8 to 1.6 Teslas for the magnetic field strength using an increment of 0.2 Teslas. Similarly examine a range of 0.7 to 0.9 for the load factor, using a range of 0.1. Examine the fluid dynamics associated with this case.

Do not consider ANY cases that drive total temperature of the plasma over 6000 K!

Requirements:

Provide the values of ***optimal*** load factor, conductivity, and magnetic field strength (the set of these three parameters that yields the lowest overall initial vehicle mass within the requested range of values). Also provide the thrust, specific impulse, mass flow rate of propellant, electric power (total) and (total) cooling (heat) rate required for this case. Tabulate and label these quantities in a single table.

For this single optimal case, plot the axial distributions of cumulative electrical power requirement developing through the channel, cumulative axial force developing through the channel, the voltage distribution through the channel, and the cumulative electric current developing through the channel. Also plot the static temperature, static pressure, axial velocity, Mach number, total temperature, and total pressure distribution along the channel (axial distribution) for this case.

Although I do not need a great deal of write-up with these results (so, in that sense, not like a 'regular' project would require), ***neatness and organization and presentation of these results WILL be factored into your grade.***