## Problem 1.

Consider a spacecraft in a circular LEO at altitude of 200km. Design a system diagram and estimate the mass and volume of a propulsion system to transfer to a circular orbit of altitude 350km. Consider your valving to protect for jet fail on/jet fail cases, as appropriate. Include propellant and N2 pressurant tanks, plumbing, valves, and a single engine for:

- (a) Monopropellant (hydrazine)
- (b) Bi-propellant (your choice)

The amount of  $\Delta V$  required for a Hohmann transfer from a 200km to a 350km orbit, under the assumption of instantaneous impulses is

$$\Delta v_1 = \sqrt{\frac{\mu}{r_1}} \left( \sqrt{\frac{2r_2}{r_1 + r_2}} - 1 \right),$$

to enter the elliptical orbit at  $r = r_1$  from the  $r_1$  circular orbit, and

$$\Delta v_2 = \sqrt{\frac{\mu}{r_2}} \left( 1 - \sqrt{\frac{2r_1}{r_1 + r_2}} \right),$$

to leave the elliptical orbit at  $r=r_2$  to the  $r_2$  circular orbit. For  $r_1=6571{\rm km}$  and  $r_2=$ 6721km, with  $\mu = 398600.4 \text{km}^3 \text{s}^{-2}$ , the total  $\Delta V$  required is 87.3 m s<sup>-1</sup>.

Engine	Type	Mass (kg)	Propellant	Thrust (N)	SI (s)
MR-80B	Monoprop	8.5	Hydrazine	3,780	225
R-40B	Biprop	6.8	NTO (MON-3)/MMH	4,000	293

Table 1: Information on the two engines used for this analysis.

To calculate our change in mass, we can use the rocket equation,

$$\frac{M_i}{M_f} = exp(\frac{\Delta V}{g_0 \cdot \text{ISP}})$$

$$\frac{M_{fuel} + M_f}{M_f} = exp(\frac{\Delta V}{g_0 \cdot \text{ISP}})$$

$$M_{fuel} = M_f \left( exp(\frac{\Delta V}{g_0 \cdot \text{ISP}}) - 1 \right),$$

which shows that the required  $\Delta V$  is a function of the initial mass of the craft. For a small satellite with a mass of 500kg, the required mass for fuel is listed in Table 2.

To calculate the volume required for the burn, we can simply calculate  $V = m/\rho$ . Hydrazine has a density of 1011 kg m<sup>-3</sup>, and for 20.19 kg of fuel this results in a required volume of  $0.0200 \, m^3$ . For the bipropellant, we need to mix fuel and an oxidizer at a mass ratio of MON/MMH= 2.16. This results in 10.54 kg of fuel, and 4.88 kg of oxidizer. MON has a density of 1442 kg m<sup>-3</sup>, and MMH has a density of 880 kg m<sup>-3</sup>. This results in tank volumes of .0073 m<sup>3</sup> and .0055 m<sup>3</sup>, respectively.

Engine	SI (s)	$\Delta V$ (kg)	Volume (m <sup>3</sup> )
MR-80B	225	20.19	0.0200
R-40B	293	15.43	0.0128

Table 2: Information on the two engines used for this analysis.

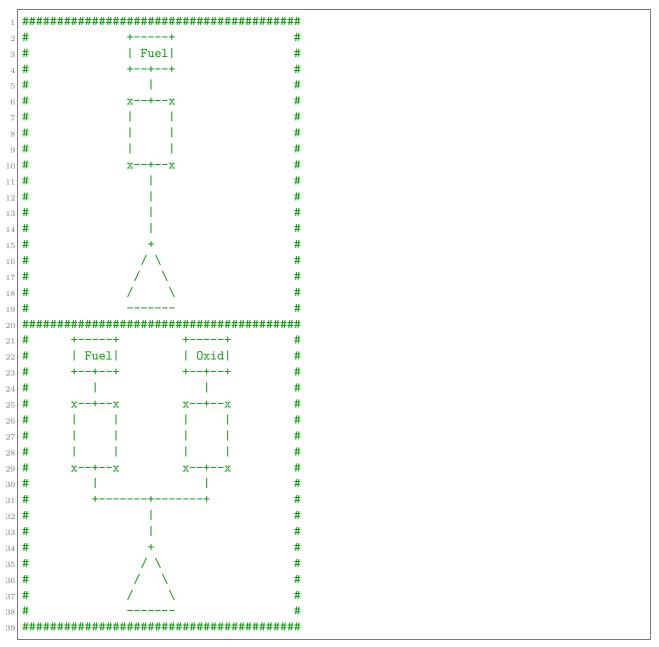


Diagram 1: Serial and parallel valve designs for monoprop and bipropellant systems. Each x represents a valve.

## Problem 2.

Read "Mission Analysis for a Micro RF Ion Thruster for CubeSat Orbital Maneuvers"

- (a) Which propulsion system included in the paper would you choose for a maximum orbit change given mass and volume constraints?
- (b) What is the chemical name and estimated ISP for the propellant of the system chosen in a)?
- (c) If you wanted to minimize propellant usage for the circularization burn of a Hohmann transfer, where on the orbit would you burn?
- (d) For use on a 3U CubeSat, what is the total mass and volume of the thruster, propellant, and tank chosen in a)?
- (e) What is the nominal thrust level and input power required? Why is input power required at all?
- (f) Why is the propellant you have chosen any better than hydrazine?
- (g) What is the main reason that you cannot instead use the Aerojet/Rocketdyne MPS-110 Cold-Gas Thruster system for CubeSats?

## Problem 3.

Read "Using Additive Manufacturing to Print a CubeSat Propulsion System"

(a) One problem encountered was arcing between a ground wire and the thruster sheath, and of course you worry about thermal containment with a spark-powered thruster in a plastic spacecraft. What would be your recommendation of a less challenging thruster system to study for incorporation into a 3-D printed CubeSat bus? Pros and cons?