NYC Aerospace Rocket Program

NYC Aerospace's 100,000ft rocket program is committed to designing and manufacturing a sounding rocket to reach 100,000ft, above 99% of the atmosphere. The purpose of this mission is to research the applications of ammonium perchlorate composite propellant (APCP) to large rockets. Many future aerospace engineers have learned a great deal about rocketry from participating in this project, which is one of NYC Aerospace's many projects involving students citywide.

Rocket details

Our goal is to send a single-stage rocket to 100,000ft using ammonium perchlorate composite propellant (APCP). In order to reach this altitude, the rocket will likely need to maintain structural integrity at velocities on the order of Mach 2 and above. Therefore, the rocket body will need to be made of a light metal such as aluminum or titanium. A metal body necessitates the capacity of the rocket motor to be in the O range of near 30,000Ns of impulse. Assuming a perfectly efficient motor, this requires around 30lb of propellant. We can calculate fuel fraction by first establishing our delta v budget.

$$\Delta v = \sqrt{2gz} = \sqrt{2(9.8m/s^2)(30480m)} = 772\text{m/s} = \text{mach } 2.25$$

Using the delta v necessary, we can calculate the minimum fuel fraction using Tsiolkovsky's ideal rocket equation. Assuming the specific impulse of our motor is 228s:

$$\Delta v = -v_e ln \frac{m_{final}}{m_{initial}}$$

$$\frac{m_{final}}{m_{initial}} = exp(-772/2280) = 0.71$$

Thus, we only need 29% of our rocket to be fuel. This brings the max mass of our rocket to 103lb. However, these equations are approximations of an ideal situation with no drag, so we must plan on needing more than 35% weight fraction of fuel. Even still, drag and gravity will be extremely significant. These calculations are included as a precaution.

Motor calculations

We will use a specific formula of ammonium perchlorate composite propellant developed by MIT known as "Cherry Limeade." Using the publicly available data on this propellant, we can calculate ideal chamber pressure and expansion ratio. Using this data we can calculate ideal motor properties. For our propellant, we know all the relevant constants:

Propellant density: $\rho_p = 1680 g/m^{-3}$

Ratio of specific heats: k = 1.21

Molar product mass: M = 23.67g/mol

Universal gas constant: R = R'/M = 326 N-m/kg-K

Propellant burn rate coefficient: a = 3.51705E-5

Propellant burn rate exponent: n = 0.3273

Burn temperature: 6300 R

Motor Requirements

Average pressure: 750psi

Average thrust: 17793N

Burn duration: 8s

Operating temperature: 70 F

Using this, we can calculate Optimal expansion ratio, $\frac{A_e}{A^*}$.

$$\frac{A^*}{A_e} = \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \left(\frac{P_e}{P_0}\right)^{\frac{1}{k}} \sqrt{\left(\frac{k+1}{k-1}\right)\left[1 - \left(\frac{P_e}{P_0}\right)^{\frac{k-1}{k}}\right]}$$

$$\frac{A_e}{A^*} = 2.968$$

Calculating thrust coefficient

$$C_F = \sqrt{\frac{2k^2}{k-1}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}\left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}\right]} = 1.591$$

Additionally, we can calculate throat area:

$$A_t = \frac{F}{P * C_F} = 3.34 in^2$$

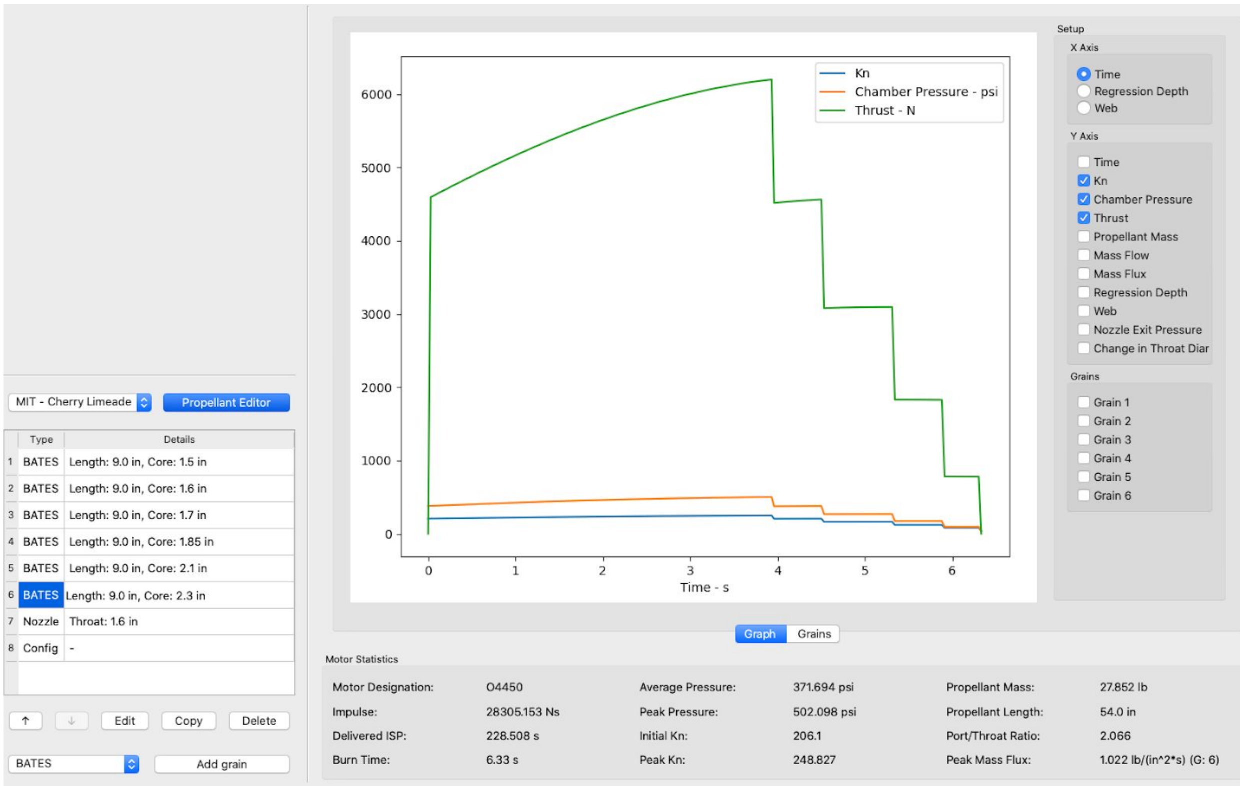
Burn rate:

$$r = ap^n = .2189 in/s$$

Burning area:

$$A_b = \frac{A_t p_1 \sqrt{k[2/(k+1)]^{\frac{k+1}{k-1}}}}{\rho_b r \sqrt{RT_1}} = 1082.104 in^2$$

Using lagrangian and differential evolution optimization, we can calculate the ideal dimensions of our rocket motor and grain size and geometry. Below is a OpenMotor simulation of the specifications. For this, I assumed we would use a finocyl grain design to maximize volumetric efficiency, have a neutral burning profile, and prevent grain collapse. As the burning area changes minimally compared to a BATES grain, the mass flux remains stable.



The dimensions of the motor, while being slightly volumetric inefficient, are very good aerodynamically. It has a diameter of 12in and a length of 35in. It will need to be manufactured from 7/8in thick aluminum casing, calculated based off of theoretical bursting pressures to allow twice peak expected pressure. The current design is very fat, but I have concluded that a significantly thinner motor with the same power is impossible based off of our current propellant. I would very much like to work on decreasing the width and increasing the height of the motor. I ran a differential evolution algorithm to optimize the grain for over a week without it being able to find a solution.We have been experimenting over the past few days I with different restraints.

Rocket Motor Manufacturing Process

We will first need to mix our ingredients as follows:

- Hydroxyl-terminated polybutadiene (HTBP) binder 10.883%
- IDP 4.275%
- MDI 1.942%
- Castor Oil 0.3%
- PDMS 0.05%
- Triton X100 0.05%
- Aluminium 7.5%
- 200um ammonium perchlorate 65.5%
- 90um ammonium perchlorate 9.5%

After mixing, we will need to cast our grain. We will either 3D print a mold, or use a styrofoam bore to our specifications and let it cast in a vacuum chamber to remove air pockets. A 3D printed bore will have the disadvantage of having ridges, increasing surface area, but is easier to create to precise specifications. We can dissolve a styrofoam bore in acetate after casting.We will need to first sand our bore to make sure the sides are smooth, causing no excessive surface area on the casted grain.

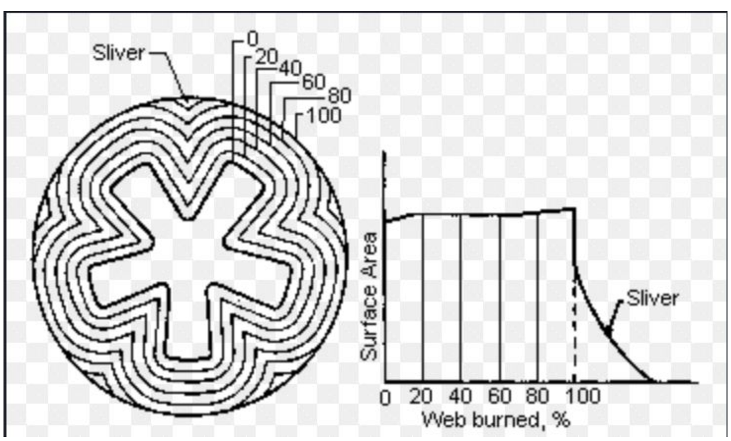
Propellant grain manufacturing process

1. Add HTPB, IDP, and Castor Oil
2. Mix for 5 minutes
3. Add AL
4. Hand mix until wetted out, machine mix for 10 minutes
5. Add PDMS and Triton X-100
6. Mix for 30 minutes

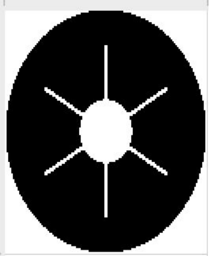
7. Vacuum for 45 minutes
8. Repeat until all 200 AP is in:
    a. Add a third of the original mass of AP
    b. Mix for 1 minute
    c. Scrape down
    d. Mix for 10 minutes
9. Add the 90 AP
10. Mix for 1 minute
11. Scrape down
12. Mix for 45 minutes
13. Add curative
14. Mix for 20 minutes
15. Vacuum for 45 minutes

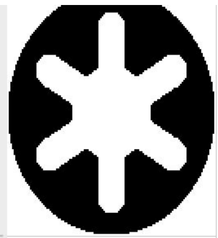
Designing the motor

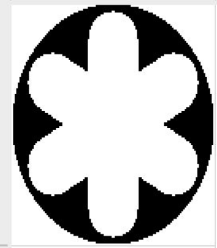
The grain will be finocyl shaped, with n = 6 (example pictured below shows n=5) prongs in a rectangular shape protruding off of the star, which maintains a constant inner surface area as the star continuously expands. Below is an example of the burn lines over time for this type of design.



This example shows how the burnlines will move throughout the rocket, however our motor has a different starting shape.

	1
Port	
Mass	192.417 lb
Mass Flow (Port)	0.0 lb/s
Mass Flux (Port)	0.0 lb/(in^2*s)
Web	3.079 in

Port	
Mass	130.638 lb
Mass Flow (Port)	20.066 lb/s
Mass Flux (Port)	0.459 lb/(in^2*s)
Web	2.384 in

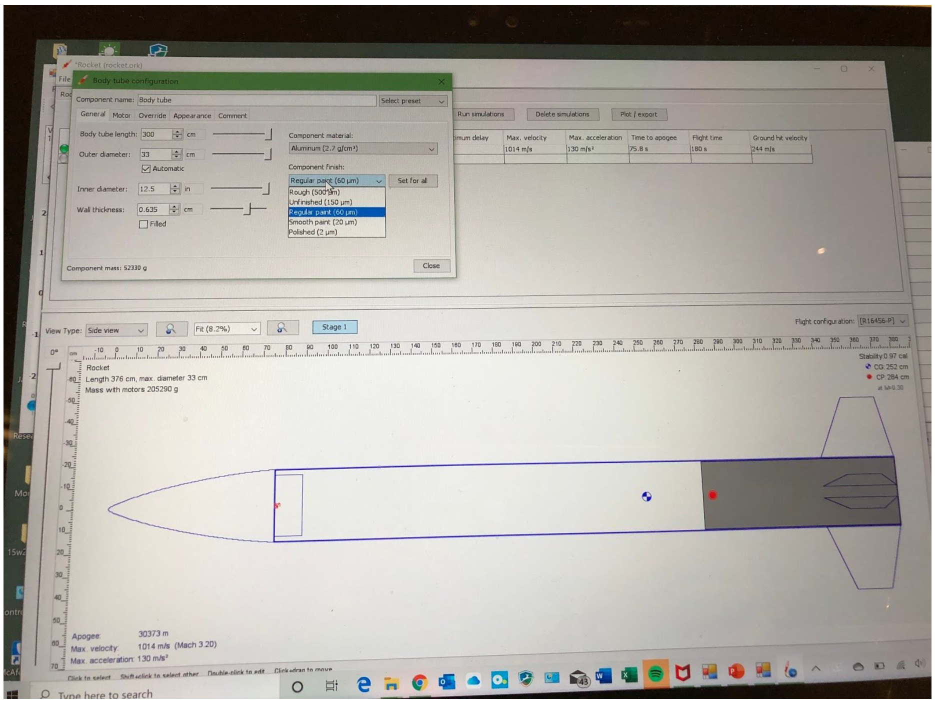
	1
Port	
Mass	71.278 lb
Mass Flow (Port)	19.323 lb/s
Mass Flux (Port)	0.256 lb/(in^2*s)
Web	1.698 in

The white shows the empty area of the fuel or the port, while the black is the remaining fuel left to be burnt. The inner circle within the port has a starting radius of 1.6” and eventually grows to accommodate the entire cylinder.

In between propellant and motor casing will be insulator to prevent the motor casing from failing. An in depth heat transfer analysis will need to be conducted to confirm that the motor casing remains at stable operating temperatures. We will use CCF (chopped carbon fiber) and aramid fiber in pulp form as reinforcement for ethylene propylene diene monomer (EPDM) as reinforcement for ethylene propylene diene monomer (EPDM) as reinforcement for ethylene propylene diene monomer (EPDM).

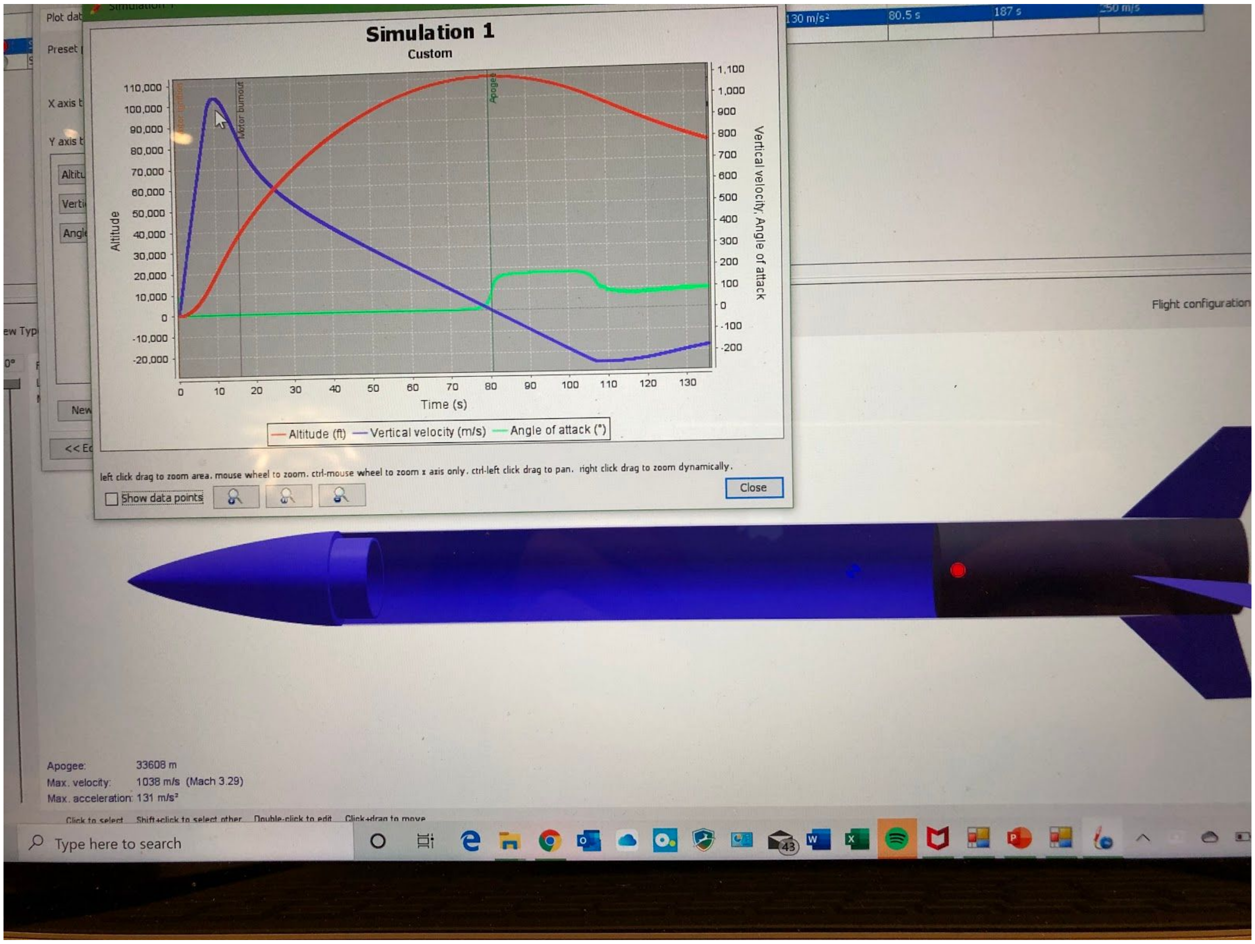
The nozzle throat will need to be manufactured from a carbon phenolic, tungsten, or titanium block on a lathe. Other components of the nozzle can be made of silica phenolic for a lower mass. The nozzle and motor casing will need to be CNC milled and welded. The chemical manufacturing of the motor will be done on-site by us.

Rocket body and Nose Cone specifications



The rocket body is 148.031 inches long made out of aluminum, with an outer diameter of 13” and an inner diameter of 12.5”. The center of gravity is 99.2126” from the top, and the center of pressure is lower at 112.992”.

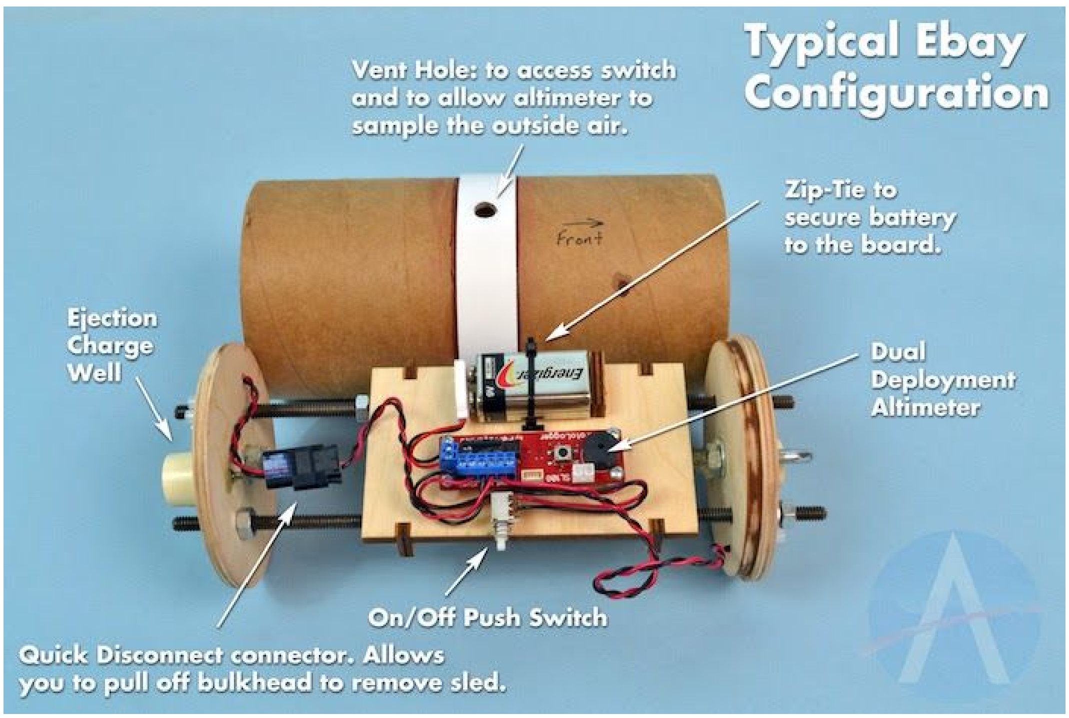
We will use 4 fins, each of which are 0’’ above the base with a height of 11.81”, a root chord of 14.5”, a tip chord of 16.7”, a sweep length of 5’’, a sweep angle of 45 degrees, and a cant angle of 5 degrees. The below simulation shows the altitude, vertical velocity, and angle of attack of the rocket.



The nose cone is 30", with a base diameter of 13" and a wall thickness of .25". The nose cone is a Haack Series Van Karman Ogive shape for maximum efficiency, which was derived using the openrocket simulator, and can be printed via solidworks by being generated on Matlab. The matlab generation code is . Unlike the body, the nose cone is made out of steel in order to move the center of gravity of the rocket above the center of pressure.

Payload and Landing System

Our landing system will involve two dual deployed parachutes controlled with an electronic GPS tracker and telemeter, specifically, the TeleMetrum system linked below. The TeleMetrum will be mounted onto a wooden sled piece held together by two 0.4” metal rods which log flight data and deploy the drogue and main parachute. Both deployments will be ground tested before. We will follow the recommended Apogee rockets configuration for setting up our dual deployment altimeter, but with 12.5” aluminum plates at the edges, and a vent hole that lines up and pokes through the body.



For CAD:

Top cylinder: 1” thick, 12.49” thick with 4 holes with 0.5” radius equidistant from each other and not along the diameter with and 2 holes along diameter 5” from the center on each side

Bottom Cylinder with same dimensions without the 4 holes

2 rods of 0.5” diameter and 8” long

Middle box is 5” wide by 5” long by 0.5” thick

A 3.7v LiPo battery will be used for the TeleMetrum and adapter, and will allow us to track the rocket’s altitude and velocity at all times for the duration of the flight. Above the top plate, we will mount a baomain pneumatic air cylinder and attach a 12.4” cyllinder, which will point towards an inwardly attached nose cone with four .125” polystyrene 60 lb force shear pins screwing in the nose cone to prevent it from being pushed out before the cylinder activates. Upon activation, the pneumatic cylinder will push the nose cone out of the rocket body breaking the shear pins, and deploying the parachutes. A tubular kevlar shock cord will connect the parachutes, the nose cone, and body.

TODO

- Risks and mitigation
- Ventilation
- Exact Parachute Deployment Time
- Nuts and Bolts

Links:

Altimeter Information:

https://www.apogeerockets.com/downloads/PDFs/AltusMetrumUserManual_20160904.pdf

References

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.871.7749&rep=rep1&type=pdf

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19770023227.pdf

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