

Aim

Our goal for this year is to build a simple hybrid engine that would allow us to go for a space shot. As the definition for space we will be using the Karman line, which is at 100km.

Vehicle

To estimate the dimensions and the performance characteristics of a rocket that we could reach space with we are taking our current construction methods for building rockets. This design utilizes of the shelf carbon fibre tubing and custom machined aluminum coupling rings to allow a modular design of the rocket. As these sections are of known weight per length and per added module this allows us to estimate what a space shot rocket would weigh. We are also confident to be able to mount the engine tank and any plumbing in the current design without adding significant weight

Part	Mass	Count	Mass total
Fin section	1kg	1	1kg
Main parachute bay	1kg	1	1kg
Drogue parachute bay	0.5kg	1	0.5kg
Nose cone	0.5kg	1	1kg
Avionics	1kg	1	1kg
Tank section outer shell	1kg	1	1kg
Coupling rings	0.15kg	5	0.75kg
Nitrous tank (dry)	?	1	?
Plumbing	?	1	?
Engine (dry)	?	1	?

Table 1: Proposed Aberdeen space shot rocket mass

Table 1 shows an overview of each module of the rocket and what we expect it to weigh. It can be seen that we expect the entire launch vehicle to come in at around 6.25kg, excluding the nitrous tank, engine and plumbing. Making a pessimistic guess that these systems would come in at 13.75kg, resulting in a total dry mass of the launch vehicle of 20kg. Any additional mass savings would then go towards a potential payload.

Based on engine sizing, which we'll go into detail later on, we'll be going with a diameter radius of 160mm for the following calculations.

Flight simulation

To estimate the altitude reached by such a vehicle we have written a simple python simulation. It assumes the following equation to calculate the acceleration of the rocket:

$$a(t) = g + \frac{F_t(t) + F_d(t)}{m(t)} \quad 1$$

where g is acceleration due to gravity, F_t the thrust produced by the engine, F_d the drag force and m the current mass of the rocket.

The mass is made up of a dry mass component and the fuel/ox mass: $m(t) = m_d + m_f(t)$. Thrust is defined as:

$$F_t = \begin{cases} 0 & \text{if } m_f \leq 0 \\ F_{\text{design}} & \text{if } m_f > 0 \end{cases} \quad 2$$

Finally the drag is given by:

$$F_d = \frac{1}{2} * \rho_{\text{air}}(h) * C_d(M) * A * v(t)^2 \quad 3$$

with ρ_{air} being the density of the atmosphere, $C_d(M)$ the coefficient of drag at a given mach number M , A the cross sectional area of the rocket ($A = \pi r^2$) and $v(t)$ the velocity of the rocket. The mach number M being defined as $M = \frac{v}{c}$ where c is the speed of sound itself defined as $\sqrt{\gamma_{\text{air}} * R_{\text{air}} * T_{\text{air}}}$, using the well known thermodynamic properties of air and its temperature (more on this further below). As the current acceleration of the rocket is itself dependent on the velocity Equation 1 becomes a differential equation, which we solve computationally using the euler method.

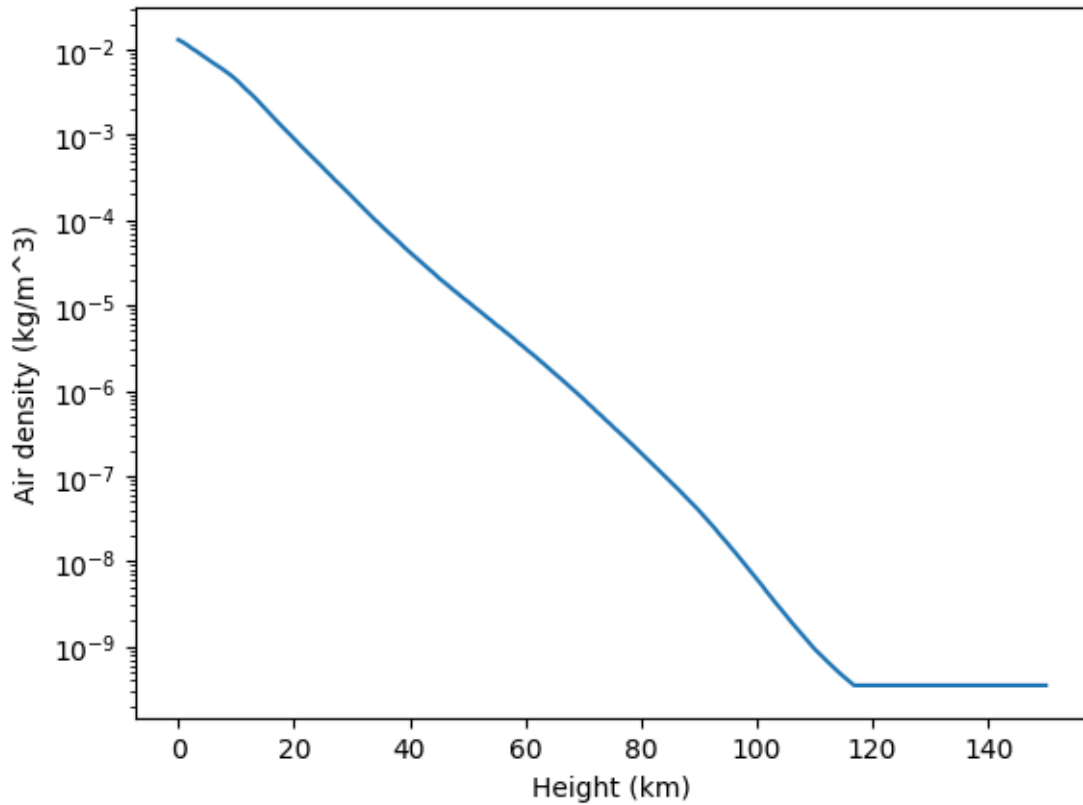


Figure 1: Air density at different altitudes from the CIRA-86 dataset

To model the atmosphere's pressure and temperature, and therefore density we are using the COSPAR International Reference Atmosphere (CIRA-86) [1] at a latitude of 67 (Aberdeen) at an annual mean. A plot of this density) at different altitude can be seen in Figure 1.

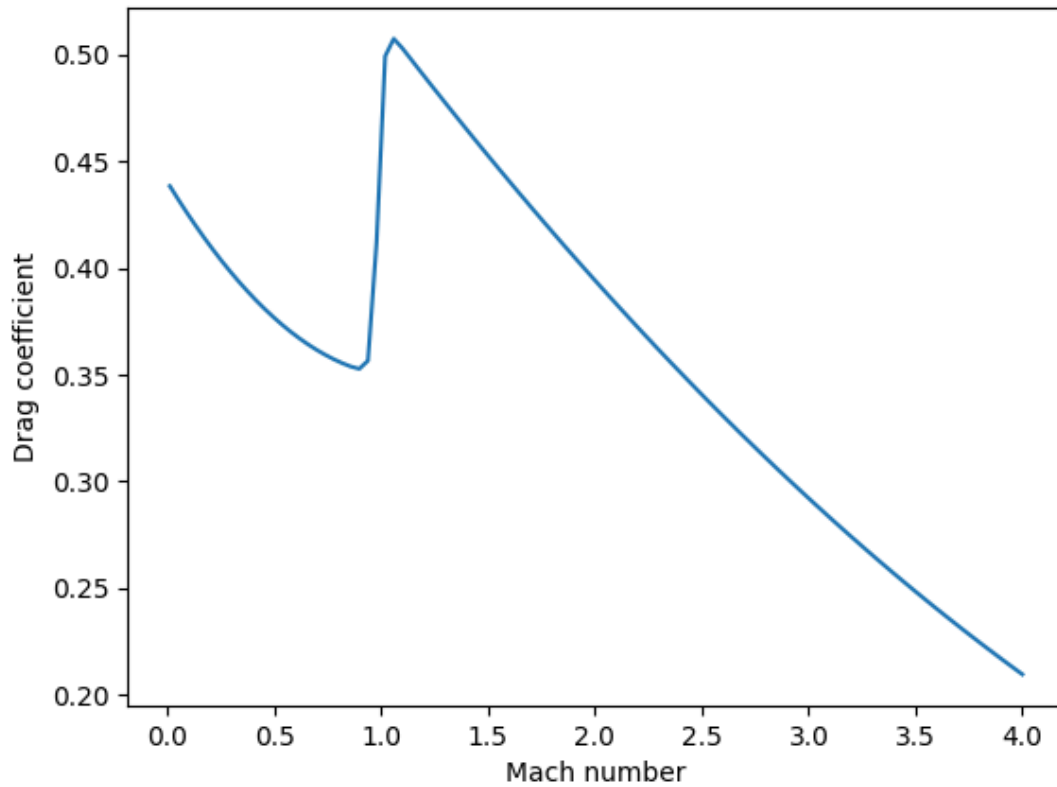


Figure 2: Drag of the Mjoellnir rocket at different Mach numbers

To calculate the drag of the rocket we are using data obtained by M. S. d. Filippi [2]. The drag obtained for the Mjoellnir launch vehicle presented in that study can be found in Figure 2. The vehicle should be similar enough to our eventual vehicle to offer a suitable approximation. We applied an additional factor $C_{d, \text{Aberdeen space shot}} = 1.2 * C_{d, \text{Mjollnir}}$, to account for potential worse than expected air resistance of our vehicle

Based on this setup we estimate that we need a fuel plus oxidizer mass of around 25kg. The flight profile resulting from such a simulation can be seen in Figure 3.

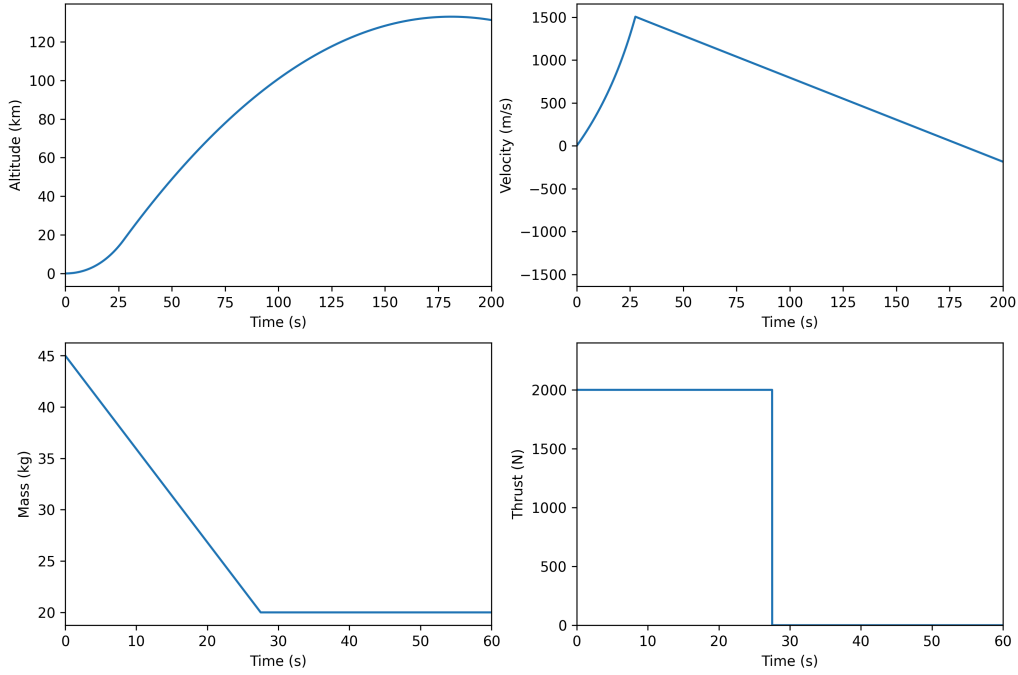


Figure 3: Simple flight simulation for the proposed Aberdeen space shot rocket

Engine sim

[Add description of NitrousEngineSim]

Based on the fuel mass, an optimal ox ratio of 1:6, for nitrous and HDPE we can then calculate the fuel grain length using:

$$l = \frac{m_{\text{fuel}}}{\rho_{\text{HDPE}} \pi (r^2 - r_p^2)} \quad 4$$

where r is the fuel grain outer diameter and r_p the initial port size cut into the fuel. The outer diameter of the grain is governed by available phenolic liners (more on this later). For this initial calculation we are going with the PT-3.9 by Blackcat Rocketry [3], with an outer diameter of $r \approx \frac{99\text{mm}}{2}$. As an initial port size we are using $r_p = 0.15$ mm based on successful ignition and operation with our previous motor. This gives us a fuel grain length of $r \approx 450\text{mm}$.

Paramter	Value
Pre combustion chamber length	0.06 mm
Post combustion chamber length	0.04 mm
Nozzle efficiency	1
Nozzle area ratio	3
Engine orifice number	5
Ox pressure	50 bar

Table 2: Engine simulation parameters

Simulating an engine with parameters from Table 2 results in the performance paramters seen in Figure 4

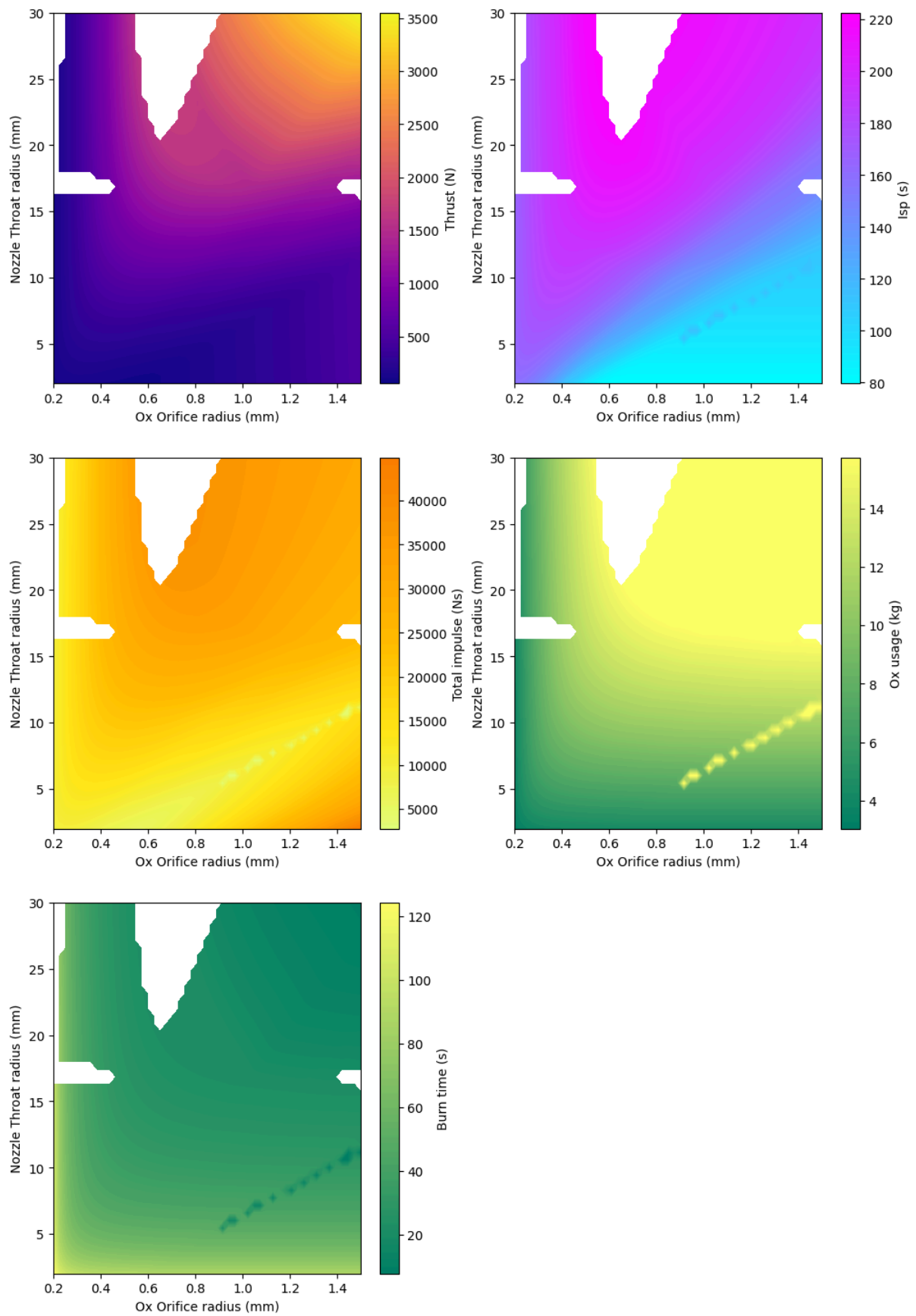


Figure 4: Engine simulated for different ox injector radii and nozzle areas

Bibliography

- [1] N. N. S. S. D. Center, "COSPAR International Reference Atmosphere (CIRA-86): Global compilations of ground-based, radiosonde, NIMBUS satellite and MSIS-86 model data from 1963-1973." [Online]. Available: <https://catalogue.ceda.ac.uk/uuid/d758b820b4eba646ff0d6c05b552e23d/>
- [2] M. S. D. FILIPPI, "Finding an Empirical Model for a Rocket's Drag Coefficients: A Comparative Analysis with OpenRocket," 2024.
- [3] "Seamless Phenolic Airframe Tubes." [Online]. Available: <https://www.blackcatrocketry.co.uk/products/phenolic-airframe-tube?variant=12103499350136>