LEVEL ONE ROCKETRY REPORT

Group #25

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PROPULSION

A rocket is propelled by the expulsion of exhaust generated by burning fuel. By Newton's 3rd Law, the expulsion of exhaust downwards exerts an equal and opposite force on the rocket, pushing it upwards. This upwards force is referred to as thrust.

Mechanics of Solid Rocket Motors

A solid rocket motor is a rocket engine which uses a solid propellant. The propellant is a combination of solid fuel and gas oxidizer. Once ignited, the propellant burns until finished, which provides a thrust force throughout the flight of the rocket [1].

Fuel Compositions

The main considerations when deciding on fuel composition are the stoichiometric ratio, the choice of reactants, the specific energy, and the burning temperature. The stoichiometric ratio is the optimal ratio between the amount of fuel and oxidizer which maximises the exhaust produced. Choosing reactants with high specific energy results in more energy output per unit mass of fuel. Some examples of fuel compositions with high specific energy include using aluminium as fuel and ammonium perchlorate as oxidiser or using sucrose as fuel and potassium nitrate as oxidiser. Some propellants may include curing agents, phase stabilizers, and solvents. Additives, for any propellant can increase the specific energy, resulting in a more desired burn rate. An opacifier may also be added to absorb heat that may otherwise result in unpredictable burning [2].

Grain Geometry

The solid propellant has a cylindrical outside surface and a hollow inside surface. The grain geometry is the shape of the internal cross-sectional area of the propellant. Grain geometry determines how rockets thrust is distributed over time [3].

In an SRM, an igniter is placed through the inside area of the propellent grain. An electrical signal is sent to the igniter, lighting the inside walls of the propellant. When the propellant is ignited, the whole inside surface area of the grain will burn. The different propellant grain shapes will influence the burn rate, as a greater exposed surface area results in a greater burn rate. The surface area at a given time is referred to as the instantaneous burning area. The size of the instantaneous burning area can change over time depending on the grain geometry.

The burning area is proportional to the chamber pressure which is proportional to the thrust generated. As the propellant burns, hot exhaust gasses build up in the combustion chamber, and hence the chamber pressure increases. As the chamber pressure increases so does the rate at which the exhaust gasses are accelerated out the nozzle, hence a greater thrust force.

For amateur motors, the most common shape for the core cross-section is tubular. Other grain geometries include star, rod and tube, double anchor, and others, each with their own thrust curves (Figure 1).

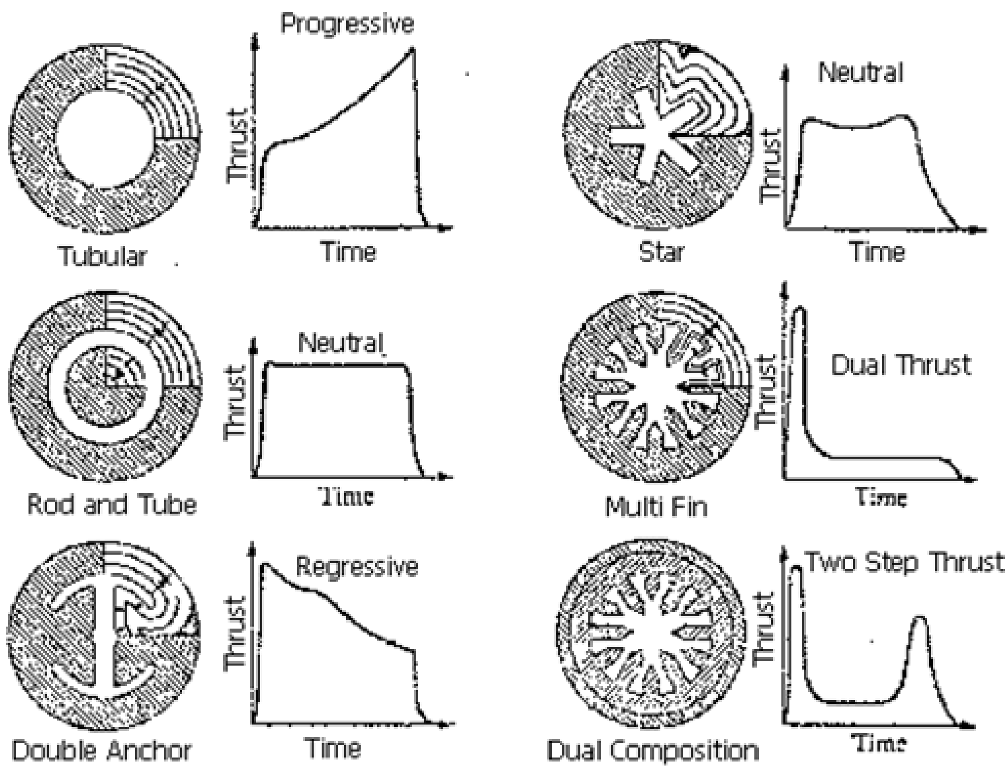

Figure 1: Grain geometries and their thrust-time curves. Image sourced from nakka-rocketry.net [4].

Since the tubular grain has a circular cross-sectional area, its instantaneous burning area increases over time. Thus, the thrust for a tubular grain increases over time. For a star shaped grain, the instantaneous burning area stays close to constant. Hence, the thrust for a star grain remains close to constant over time.

Impulse classes

The total impulse of an SRM is the average thrust multiplied by the operating time of the motor. It corresponds to the area under the thrust-time curve (Figure 1). The total impulse can be used to determine the characteristics of the rocket's flight, such as apogee and maximum speed [5]. The impulse class of a rocket motor is a letter which indicates its total impulse [6].

Rocket motors are named based on their characteristics. For instance, in the I280DM motor, the letter "I" represents the impulse class of the rocket. For a class "I" rocket the total impulse is 561 Ns. The numbers "280" represent the average impulse of the rockets motor, i.e., 280 Ns. The letters "DM" represent the propellant type, in this case "DM" stands for Dark Matter™, a proprietary propellant of Aerotech [7].

RECOVERY

When a rocket comes back down it must do so safely, without damaging the rocket. This is so that it can be flown again without spending money fixing equipment/parts. To safely bring the rocket back down to the ground, recovery mechanisms are used.

Recovery mechanisms are devices which slow the rocket down after it has reached peak altitude so that the rocket can be safely recovered. The two most common types of recovery mechanisms are parachutes and streamers. Both methods rely on using air resistance to slow down the rocket [8].

Recovery Methods

Parachutes use a sheet with a large surface area to generate air resistance which slows the descent of the rocket. Streamers use a length of fabric which flutters in the air to produce drag [9]. Streamers produce less drag than parachutes and thus result in a faster descent speed. Hence, streamers are mainly used for low-mass rockets. The advantage of streamers over parachutes is that they result in less drift, and thus the rocket is easier to recover after it has landed.

We chose to use a parachute in our design since a parachute will provide more air resistance, which will result in safer landing. Additionally, parachutes are more commonly used and recommended by UC Aerospace.

Deployment Methods

This section aims to find a suitable method for deploying the parachute, and more importantly how to deploy the parachute at the correct time. There are few options when it comes to deployment methods. The recommended method is using motor ejection in conjunction with a black powder charge.

The use of an accelerometer can be used to launch a parachute as it identifies when the rocket is at apogee. This then triggers a black powder charge to deploy the parachute. The benefits of this system are consistent performance rather than time-based deployment. The disadvantages of accelerometer-based deployment are that it is more expensive and complex.

The other deployment option, that is recommended, is to use motor ejection and a black powder charge. The motor ejection is on a built-in delay after burnout. For the motor in the patriot kit, the delay is 14 seconds. The black powder charge is then triggered, which causes the nose cone to come off, and the parachute to be ejected.

Drogue parachutes are used for high altitude launches, where dual deployment is used. The drogue chute is deployed at apogee. This slows the descent before the main parachute is deployed. If we want the main parachute to deploy at ~200m altitude, we will need an altimeter to trigger a black powder charge at this altitude.

Safe Landing Speed

To safely recover the rocket, the rocket must decelerate to a suitable landing speed. According to our OpenRocket model, the mass of our rocket is 1.675 kg. The Rocketman 4 ft (1.22 m) standard parachute [10] recommended for the OpenRocket design will achieve a descent speed of 17 ft/sec (18 km/h) for a weight of 3.7 lb. This is an acceptable landing speed as recommended by UC Aerospace tutors.

AEROSTRUCTURE

Stability

The stability of a rocket depends on its centres of gravity and pressure. The centre of gravity is the point in the rocket where the weight of a body or system is considered to act. The centre of pressure is the point where the aerodynamic pressure of the atmosphere is considered to act. If the centre of gravity is above the centre of pressure, the rocket is stable. If not, the rocket is unstable [11].

Stability is quantified using the calibre of stability, abbreviated as cal. The calibre of stability is determined by the ratio between the distance between the centre of gravity and centre of pressure and the diameter of the rocket. In general, a stable rocket should have a calibre of stability between 1.5 cal and 5 cal [12].

Fins

Fins are used for stability, control, and safety of the rocket. Fins increase the surface area of the lower end of the rocket, which lowers the centre of pressure, and thus increases the stability of the rocket. A more stable rocket is easier to control, and a rocket which is easier to control is safer. Simulation software is used to determine the appropriate size and shape of the fins to ensure a given calibre of stability. Wind tunnels can be used to physically test the effectiveness of fins.

Nose cone

A nose cone reduces air resistance and improves stability. The most used types of nose cones are conic, blunted conic, bi-conic, ogive, elliptical, and parabolic. These different nose cone shapes are depicted in Figure 2. Conical designs are easy to manufacture but are less streamlined than elliptical or parabolic designs. The tangent ogive is frequently used for model rockets since it is aerodynamically optimal.

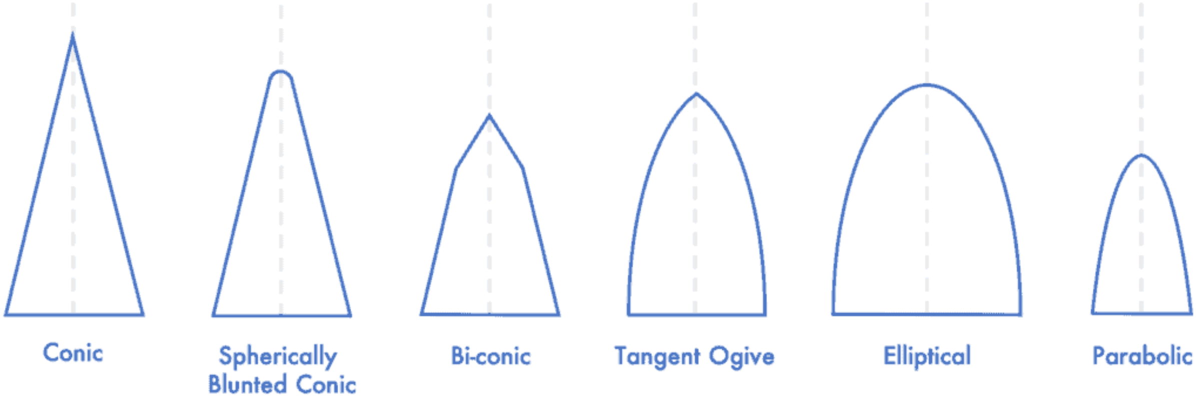

Figure 2: Various nose cone designs. Image sourced from themodelrocket.com [13].

Materials

The materials used for the ¼ scale Patriot kit include aluminium, brass, Kevlar, fibreglass, plastic, plywood, phenolic, and vinyl. Other materials are typically used for level 2 and level 3 rockets, including nylon and filament.

OPENROCKET

Using the rocket optimisation features in OpenRocket, we found fin designs that were optimal for maximising speed, maximising apogee, and maximising both speed and apogee whilst retaining a stability of 1.6 cal (Table 1).

Table 1: Parameters of optimal fin designs

Fin type	Maximise Speed	Maximise Apogee	Maximise Both with 1.6 cal stability
Trapezoidal	Tip chord = 60.9 mm Sweep = 105 mm Root chord = 135 mm Height = 59.9 mm	Tip chord = 60.9 mm Sweep = 105 mm Root chord = 159 mm Height = 59.9 mm	Tip chord = 61.6 mm Sweep = 122 mm Root chord = 162 mm Height = 82.3 mm
Elliptical	Height = 74.6 mm Root chord = 48.8 mm	Height = 74.0 mm Root chord = 50.6 mm	Height = 85.0 mm Root chord = 60.2 mm
Freeform	For freeform fins, OpenRocket has no means of optimising the shape. Hence, only one freeform fin shape was used for scoring. Its coordinates are: (0,0), (4,9), (9,8), (7,0).		

Tube fin	Similarly, OpenRocket has no means of optimising the parameters of tube fins. Thus, the tube fin design used for scoring has the following parameters: 6 tube fins, Length = 100 mm, OD = 102 mm, ID = 100 mm

These fin designs were then scored using Equation 1:

$$Score = (Apogee + 6 \cdot Max.Velocity) \cdot \left(1 - \frac{|Stability - 1.6|}{1.6}\right) \quad (1)$$

These scores are listed in Table #.

Table 2: Scores of each fin design

Fin design	Apogee / m	Max. Velocity / m/s	Stability / cal	Score
Trapezoidal 1	801	185	0.447	533.9
Trapezoidal 2	796	184	0.422	501.1
Trapezoidal 3	760	180	1.6	1840
Elliptical 1	745	183	1.0	1152
Elliptical 2	746	183	1.0	1153
Elliptical 3	728	181	1.61	1803
Freeform	708	171	1.57	1701
Tube fin	595	150	2.99	196.2

The fin design with the best score was the trapezoidal design maximising both speed and apogee whilst constraining stability to 1.6 cal.

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