Rocketry 101

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Propulsion

A rocket generates thrust by having a greater force than the others being applied to it. Newton's third law states that "For every action there is an opposite and equal reaction." Applied to a rocket this means that the force of the pressure of the gas being pushed out of the rocket nozzle must be greater than the forces like gravity or drag that are trying to keep it grounded.

A solid rocket motor works through the combustion of the chemical combination of the fuel and oxidizer and how the propellant grain is consumed in these reactions, how the exhaust gasses flow and form at the burning surface, travel through the chamber, and exit through the nozzle to interact between these exhaust gasses and, condensed particles of smoke.

The fuel composed of the fuel and oxidizer can be simple, such as with the "sugar" based propellant. Experimental composite propellants can be more complex and can contain a variety of different oxidizers as well as metals like aluminum and magnesium. You might use different fuel compositions to achieve certain characteristics. This could be used to control the burn rate or absorb heat.

All propellants are processed in a basic geometric form which is referred to as a propellant grain which is cylindrical in shape and is fitted into the rocket motor to maximize its volumetric efficiency. The grain can contain different segments within the central core cylinder which is along the full length of the grain to increase the propellant surface area initially exposed to combustion. The core shape influences the thrust curve, as seen in Figure 1, because the thrust and chamber pressure produced by the rocket motor is proportional to the burning area at any point in time which is referred to as the instantaneous burning area.

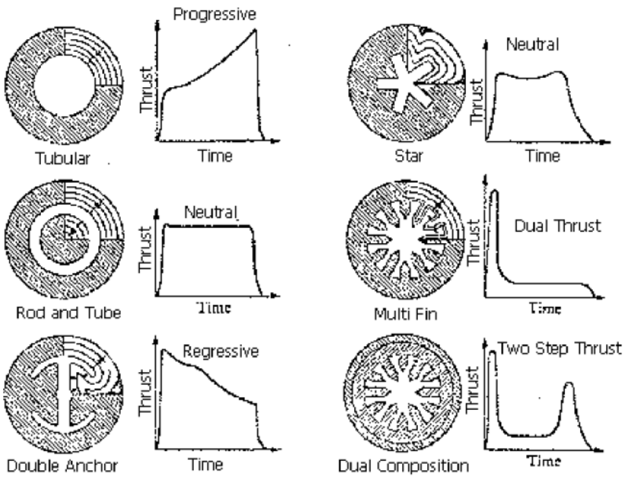

Figure 1: The effect of core shape on the thrust curve.

The burning area of the propellant grain performance determines the success of the rocket motor. A neutral burn is the most desirable one as it has a relatively constant burn which therefore maximizes the efficiency of the nozzle as it works best in a constant chamber pressure. (Nakka, 2022, pp 1-6)

Nozzles channel and accelerate the combustion products that are produced by the burning propellant to maximize the velocity of the exhaust as it exits. It achieves this by using the heat of the fluids to accelerate the flow as energy is conserved in this process. (Nakka, 2022)

The ideal motor for our use would be the Aerotech I245G-10 38/360 RMS. This motor has a high impulse and a high maximum thrust at 334.1 Kg ms^{-1} and 412.0 Newtons respectively (Apogee Components, 2022). It is also an RMS (Reloadable Motor System) which means that you can refill the propellant after each flight rather than continuously replacing the motor.

Recovery

Types of recovery

For a rocket launch to be deemed successful, the rocket must be recovered in a condition where it would be able to fly again. To achieve this, the rocket must be slowed down before hitting the ground, reducing its risk of catastrophic damage. The slowing down of a rocket is achieved through various recovery methods - design approaches which cause the retardation of descent speed, increasing chance of successful recovery. Four of the primary methods have been identified:

Parachute recovery:

Parachute recovery describes the use of an umbrella-like device used to decrease the descent speed of a falling body. The parachute’s ability to produce a large drag force results in slow descent speeds – therefore increasing the chance of a successful rocket recovery. Parachute recovery is more challenging to implement compared to other recovery methods, as the parachute is more difficult to produce, and has a more complex ejection. Their large surface area can also create large drift by wind during descent, meaning the rocket may land far from its launch point.

Streamer recovery:

This method implements strips of material to slow down descent of rockets by producing an upwards drag force. This recovery method is only appropriate for smaller or lighter rockets, due to the smaller drag force produced. Streamers are easier to produce and implement in a rocket compared to parachutes, and are cheaper to create, however, and their smaller surface area can result in less drift due to wind. (Cool Rocket Stuff, n.d.)

Helicopter recovery:

The helicopter recovery method involves the deployment of helicopter-style blades, which cause the rocket to autorotate down to the ground. This method is achieved through pressure build-up causing the nose cone of the rocket to pop off, where rubber bands connected to the blades cause them to emerge. This form of recovery method risks the rocket entering an unrecoverable spiral if knocked out of balance, however, is simple to implement.

Tumble recovery:

Tumble recovery involves the ejection charge causing the burnt-out engine to shift to the rear of the rocket, or eject entirely. This shift in mass distribution causes the rocket's centre of gravity to shift behind the centre of pressure, causing the rocket to enter an unstable spiral – the "tumble." A benefit of this recovery method is that no equipment is deployed, however this method is only appropriate for small and short rockets which are built to withstand impact with the ground. This is because this method does not sufficiently reduce descent speed for larger rockets. (Apogee Components Inc., 2017).

Methods of deployment

How do parachutes deploy?

A parachute is a dome-shaped form made of plastic or nylon, used to decrease the descent speed of rockets, and increases the chance of a successful recovery. The parachute is stored behind the rocket's removable nose cone and is attached to the main body of the rocket via lines. Parachutes are deployed with an ejection charge.

This deployment method is beneficial, because black powder is accessible, cheaper to implement into a design, and is reliable at setting off the ignition charge. Conversely, because this method involves explosives, considerations must be made. Due to the parachute (generally) being constructed from plastic, an inflammable material must be placed between the parachute and the ejection charge, to ensure the parachute will not melt before deployment. Additionally, the parachute cannot be packed too tight within the rocket, or the parachute risks not being deployed when the ejection charge goes off.

What causes deployment?

There are two primary methods for causing deployment of a parachute. The first involves using a pyrotechnic composition, black powder, as mentioned above, to create an ejection charge. Upon the main engine burning out, a short-term thrust is provided due to a build-up of pressure within the rocket, which causes the nose cone to “burst open.” This causes the parachute to deploy, slowing descent. (Nakka, 1999). This is the most common method for creating an ejection charge, due to its cheap price to implement, being easy to set up, and high success rate.

Mechanical systems using timer or electronic sensor-based systems also may be used to deploy a parachute. While black powder creates an ejection charge upon the engine burning out, a mechanical system may use a timer, where the nose cone may be opened after a certain period after take-off. Electronic components may also be used to determine the point of deployment, such as the use of an accelerometer and altimeter to determine appropriate points of the deployment of two separate parachutes. (Christian et al, 2013.)

Open Rocket

The maximum speed fin design was designed by minimising the size of the fins while keeping at least 1 calibre of stability as to make sure the rocket would still be stable. The maximum speed fin design reached a speed of 192 m/s which reached an altitude of 832m.

The maximum altitude fin design was designed by minimising the size of the fins while keeping at least 1 calibre of stability. The fins were also designed to be swept back as it moves the centre of pressure closer to the tail meaning the stability of the rocket can be increased while making the rocket more streamline. The maximum altitude fin design reached a speed of 194 m/s which reached an altitude of 843m. The maximum altitude fins are just a better designed maximum speed fin design as they reach the same maximum speed, but the maximum altitude design goes to a higher altitude.

The maximum stability fin design was designed by making the fins larger while keeping the apogee over 800m at least as that is a good height for a rocket. The maximum stability fin design reached a speed of 192 m/s or Mach 0.56 which reached an altitude of 804m and the design had a calibre of 2.9.

All the designs used the motor which was chosen which was the Aerotech I245G-10 38/360 RMS in the OpenRocket simulations got the results above. With the Aerotech H195NBT-10 motor the simulator returns the maximum altitude for the speed design as 613m, the altitude design as 621m and the stability design as 595m. The maximum velocity was 156m/s for all three designs and the stability design having 3.47 calibres when using the Aerotech H195NBT-10 motor.

Aerostructure

Aerodynamics

The stability of a rocket is dependent on the location of the centre of gravity (CG) and the centre of pressure (CP). For a rocket to be considered stable the CP must be lower than the CG as both lift and drag act through the CP and the rocket rotates around the CG. The lift and drag forces act to put the rocket back in the flight direction when knocked off course by the wind. This means that lift and drag act as restoring forces on the rocket when the CP is lower than the CG otherwise the lift and drag cause the rocket to spin around making them a de-stabilizing force (Benson, 2021). A rocket is considered stable when the CP is at least one calibre lower than the CG with a calibre being the same as the diameter of the rocket (Nakka R. , 2001).

Fins move the CP closer to the tail end of the rocket making the rocket more stable in flight with different fin designs have different effects on the CP. An airfoil is changing the cross-section of the fins which is area where the air hits the fins, an optimised airfoil is when the fins have a taper from the root of the fin to the tip of the fin. This is because a tapered airfoil has the lowest drag compared to other airfoils apart from a thin plate fin which is just a very thin fin but is more susceptible to fin flutter which causes drag to increase exponentially (Milligan, 2017). Any airfoil is better than no airfoil which is where the cross-section is rectangular meaning all fins should have some sort of airfoil as it adds more stability to the rocket. Different shapes have effects on the stability of the rocket with an elliptical shaped fin being the theoretically best fin shape, but a trapezoid or clipped delta is better in reality (Milligan, 2017). The height of the fins changes how much stability they give with a fin that is too short will not give enough stability and a fin too tall will produce too much drag meaning the rocket will not fly as high (Milligan, 2017).

Structural

The materials being used in our rocket are:

- Polystyrene. To be used as the nose cone. This material can be shaped easily into a shape necessary for this use.
- Birch Wood. To be used for motor centring rings. Birch is a hardwood that is durable but still light.
- Plywood(birch). To be used for the fins. Incredibly light and very easy to shape.
- Ripstop and Braided Nylon. To be used for the parachute canopy and shroud lines. These polymers are very strong and durable and are resistant to tearing and ripping.

- Kraft Phenolic. To be used for all other parts of the rocket. This is dielectric paper treated with resin to make it durable and strong and better performing under heat. (Paramount Tube, 2016)

Some materials commonly used in industrial rockets are:

- Aluminium. This is mostly used for the body and frame of the rocket. This is because its lightweight and very strong.
- Carbon Fibre Composites. Rocket Labs creates their electron rockets out of a special carbon composite that helps decrease mass of the rocket by around 40%. This makes it cheaper and easier to create and fly. (Rocket Lab, 2020)
- Polyester and Nylon. Used for the parachutes for NASA's Mars rover missions. Lightweight but extremely durable. (NASA, n.d)

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