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Basic Principles of Rocket Science

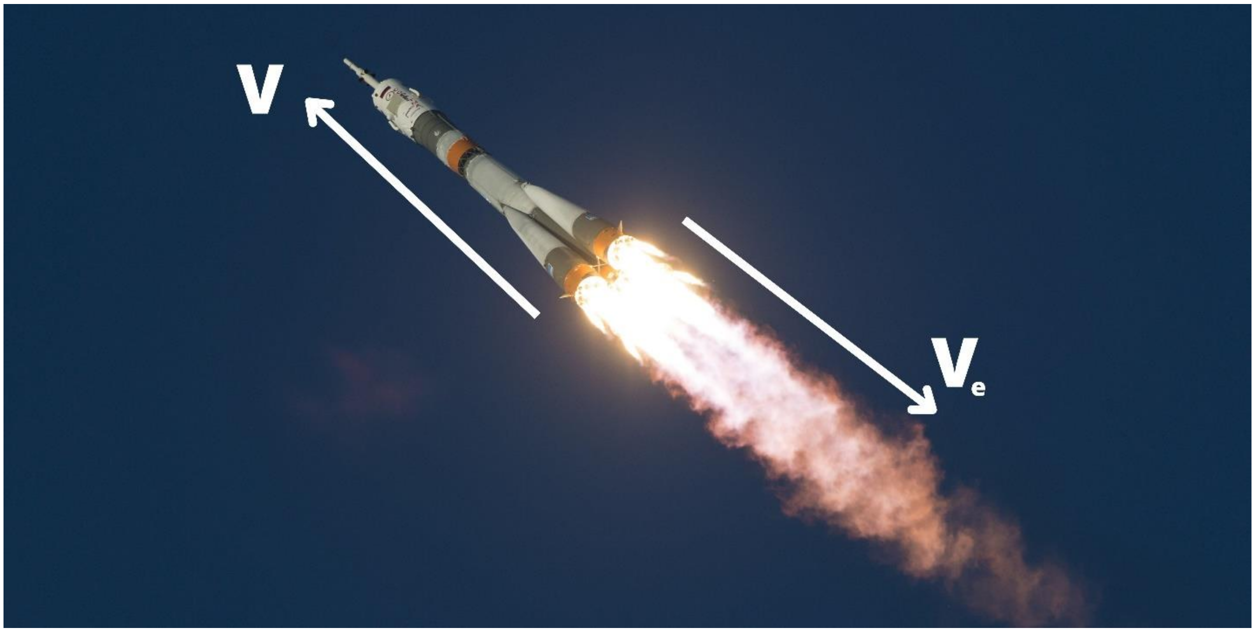
A rocket in its simplest form is a chamber enclosing a gas under pressure. A small opening at one end of the chamber allows the gas to escape, and in doing so provides a thrust that propels the rocket in the opposite direction. A good example of this is a balloon. Air inside a balloon is compressed by the balloon's rubber walls. The air pushes back so that the inward and outward pressing forces are balanced. When the nozzle is released, air escapes through it and the balloon is propelled in the opposite direction. The only significant difference is the way the pressurized gas is produced. With space rockets, the gas is produced by burning propellants that can be solid or liquid in form or a combination of the two.

A rocket works on Newton’s Third law of motion which states that “every reaction has equal and opposite reaction”. With rockets, the action is the expelling of gas out of the engine. The reaction is the movement of the rocket in the opposite direction. To enable a rocket to lift off from the launch pad, the action, or thrust, from the engine must be greater than the mass of the rocket. In space, however, even tiny thrusts will cause the rocket to change direction.

Now let’s jump into the equations involved in rocket science.

Let’s assume that the total mass of the rocket is “m” including its fuel weight. When the rocket starts to lift off then the minimum force required to move the rocket upward will be the product of mass of rocket and gravitational acceleration.

When the rocket is in the air, it will have upward velocity (V) and exhaust velocity (Ve). Also the mass of the rocket decreases as the fuel is burning out with every second. We also need to consider that in whole rocket system including the upward velocity and exhaust velocity there applies another force which is pulling the whole system downward – “Gravitational force”.



When rocket starts firing it loose mass with the passage of time as the fuel burn. Now we need to calculate the total force being applied on rocket system by gravity. Let’s assume that the rate at which rocket loose it’s mass is R (kg/sec) and time passed is “t”.

$$-mg = \left(\text{Mass of Rocket} \times \text{acceleration of Rocket}\right) + \left(\text{Mass of exhaust} \times \text{acceleration of exhaust}\right)$$

Eq. (1)

Mass of rocket = (M – R.t); R.t is defined as rate at which the rocket loose it’s mass within a given time frame

Mass of Exhaust = R.t (amount of mass that has been expelled within a given time frame)

Now comes a bit complicated part, to calculate the acceleration of exhaust. Acceleration is defined as the rate of change of velocity. Exhaust velocity goes from V (before it is expelled) to Ve (after it is expelled). This diference is in negative as the acceleration is downward direction. So the acceleration of exhaust velocity is calculated by

$$(-Ve - V)/t$$

Now putting up all the values in Eq. (1), we can derive the equation which tells us how the whole system moves

$$-mg = (m - R.t).\ a + (R.t).\ (-Ve - v)/t$$

Above equation can be further reduced as “t” will get cancelled out

$$-mg = (m - R.t).a + R.(-Ve - V)$$ Eq. (2)

The above equation shows how the whole rocket plus exhaust system moves.

What do you think should be the minimum exhaust velocity for the rocket to just hover?

When the rocket is hovering then it's velocity and acceleration are zero. In this case the Eq. (2) reduces to

$$-mg = R.Ve \quad \text{Eq. (3)}$$

But here still there are two variables to find the force required – "R" – rate at which fuel is coming out & "Ve" – Exhaust Velocity

Let's assume that the rocket exhaust has an area of "a". So the volume of exhaust coming out can be expressed as

$$Vol = a.Ve$$

Now we need to relate the volume and rate "R". Rate is expressed as kilogram of fuel coming out within a given time frame. 1 Kg is 1 L and there are 1000 litres in 1 cubic meter

So, $$R = 1000.Vol$$

Now the Eq. (3) reduces to

$$-mg = (1000.Vol).\ Ve$$

Which further reduces down to

$$V_e = -\sqrt{\frac{mg}{1000.a}}$$

This should be the minimum exhaust velocity for the rocket to hove. Just fill in all the variable i.e mass of rocket, gravitational force and area of exhaust.

The above equation is the basic equation to give an overview on how rocket works when we look from the perspective of mathematics and formulas. There are many more variables and factors present in real life situation such as temperature of gas, molecular mass of gas, absolute pressure of gas at nozzle, air resistance and many more.

But I hope that it gave you a brief description on how the system works on a basic level.