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Rocket Net Force

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***Abstract*— Net force refers to what you get when you consider the total effect of all the forces acting on something. If two equal forces are acting in opposite directions, the net force is zero. A net force acting on an object causes the object to accelerate. The study of rockets is an excellent way for students to learn the basics of forces and the response of an object to external forces. The motion of an object in response to an external force was first accurately described over 300 years ago by Sir Isaac Newton, using his three laws of motion. Engineers still use Newton's laws to design and predict the flight of full scale rockets. Forces are vector quantities having both a magnitude and a direction. When describing the action of forces, one must account for both the magnitude and the direction. In flight, a rocket is subjected to four forces; weight, thrust, and the aerodynamic forces, lift and drag.**

***Index Terms*—Rocket Net Force, Newton's Laws of Inertia, Aeronautics force, Drag, Lift, Weight, Thrust, Rocket Design.**

I. Introduction

Rocket, any vehicle propelled by ejection of the gases produced by combustion of self-contained propellants. Rockets are used in fireworks, as military weapons, and in scientific applications such as space exploration

Satellites have a major part to play in the present communication system. These satellites are launched with the help of rockets. Typically a payload will placed by a rocket in to Low Earth Orbit or LEO (around 400 km) and then boosted higher by rocket thrusters. But just transporting a satellite from the lower orbit to its eventual destination can to several thousand dollars per kilogram of payload. To cut expenses space experts are reconsidering the technology used to place payload in their final orbits. There are over eight thousand satellites and other large objects in orbit around the Earth, and there are countless smaller pieces of debris generated by spacecraft explosions between satellites. Until recently it has been standard practices to put a satellite in to and leave it there. However the number of satellites has grown quickly, and as a result, the amount of orbital debris is growing rapidly. Because this debris is traveling at orbital speed (78km/s), it poses a significant threat to the space shuttle, the International Space Station and the many satellites in Earth orbit. One method of removing a satellite from orbit would be to carry extra propellant so that the satellite can bring itself down out of orbit. However this method requires a large mass of propellant and every kilo of propellant that must be carried up reduces the weight available for revenue-producing transponders. Moreover this requires that the rocket and satellites guidance systems must be functional after sitting in orbit for ten years or more.

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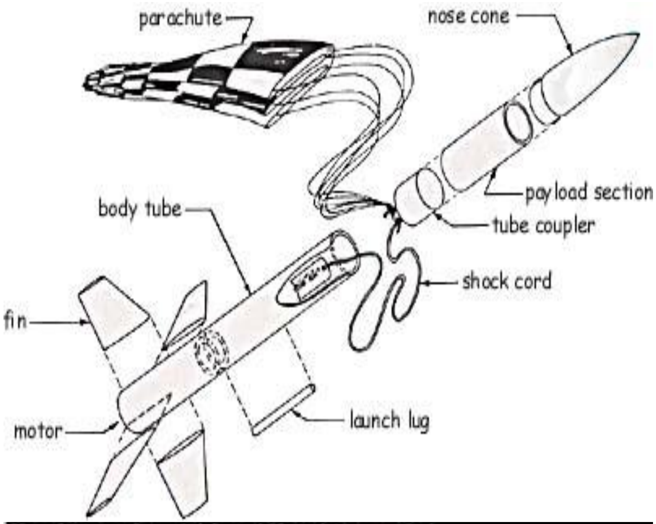
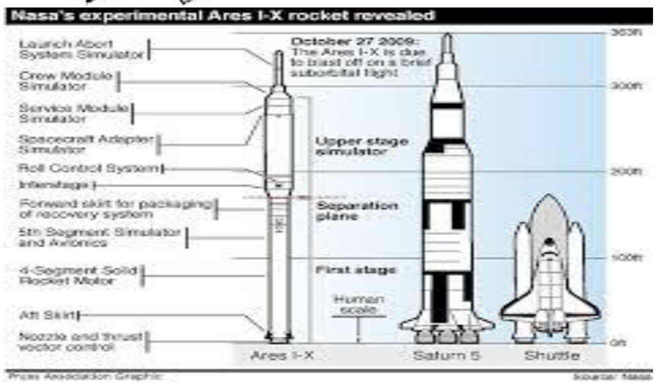
II. Rocket Design





A rocket design can be as simple as a cardboard tube filled with black powder, but to make an efficient, accurate rocket or missile involves overcoming a number of difficult problems. The main difficulties include cooling the combustion chamber, pumping the fuel (in the case of a liquid fuel), and controlling and correcting the direction of motion.

A. Components

Rockets consist of a propellant, a place to put propellant (such as a propellant tank), and a nozzle. They may also have one or more rocket engines, directional stabilization device(s) (such as fins, vernier engines or engine gimbals for thrust vectoring, gyroscopes) and a structure (typically monocoque) to hold these components together. Rockets intended for high speed atmospheric use also have an aerodynamic fairing such as a nose cone, which usually holds the payload.

As well as these components, rockets can have any number of other components, such as wings (rocketplanes), parachutes, wheels (rocket cars), even, in a sense, a person (rocket belt). Vehicles frequently possess navigation systems and guidance systems that typically use satellite navigation and inertial navigation systems.

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B. Engines

Rocket engines employ the principle of jet propulsion. The rocket engines powering rockets come in a great variety of different types, a comprehensive list can be found in rocket engine. Most current rockets are chemically powered rockets (usually internal combustion engines, but some employ a decomposing monopropellant) that emit a hot exhaust gas. A rocket engine can use gas propellants, solid propellant, liquid propellant, or a hybrid mixture of both solid and liquid. Some rockets use heat or pressure that is supplied from a source other than the chemical reaction of propellant(s), such as steam rockets, solar thermal rockets, nuclear thermal rocket engines or simple pressurized rockets such as water rocket or cold gas thrusters. With combustive propellants a chemical reaction is initiated between the fuel and the oxidizer in the combustion chamber, and the resultant hot gases accelerate out of a rocket engine nozzle (or nozzles) at the rearward-facing end of the rocket. The acceleration of these gases through the engine exerts force ("thrust") on the combustion chamber and nozzle, propelling the vehicle (according to Newton's Third Law). This actually happens because the force (pressure times area) on the combustion chamber wall is unbalanced by the nozzle opening; this is not the case in any other direction. The shape of the nozzle also generates force by directing the exhaust gas along the axis of the rocket.

C. Propellant

Rocket propellant is mass that is stored, usually in some form of propellant tank or casing, prior to being used as the propulsive mass that is ejected from a rocket engine in the form of a fluid jet to produce thrust. For chemical rockets often the propellants are a fuel such as liquid hydrogen or kerosene burned with an oxidizer such as liquid oxygen or nitric acid to produce large volumes of very hot gas. The oxidiser is either kept separate and mixed in the combustion chamber, or comes premixed, as with solid rockets.

Sometimes the propellant is not burned but still undergoes a chemical reaction, and can be a 'monopropellant' such as hydrazine, nitrous oxide or hydrogen peroxide that can be catalytically decomposed to hot gas.

Alternatively, an inert propellant can be used that can be externally heated, such as in steam rocket, solar thermal rocket or nuclear thermal rockets.

For smaller, low performance rockets such as attitude control thrusters where high performance is less necessary, a pressurised fluid is used as propellant that simply escapes the spacecraft through a propelling nozzle.

D. Exit Nozzle

A critical element in all rockets is the design of the exit nozzle, which must be shaped to obtain maximum energy from the exhaust gases moving through it. The nozzle usually converges to a narrow throat, then diverges to create a form which shapes the hypersonic flow of exhaust gas most efficiently. The walls of the combustion chamber and nozzle must be cooled to protect them against the heat of the escaping gases, whose temperature may be as high as 3,000°C—above the melting point of any metal or alloy.

III. ROCKET PROPULSION

The force acting on a rocket, called its thrust, is equal to the mass ejected per second times the velocity of the expelled gases. This force can be understood in terms of Newton's third law of motion, which states that for every action there is an equal and opposite reaction. In the case of a rocket, the action is the backward-streaming flow of gas and the reaction is the forward motion of the rocket. Another way of understanding rocket propulsion is to realize that tremendous pressure is exerted on the walls of the combustion chamber except where the gas exits at the rear; the resulting unbalanced force on the front interior wall of the chamber pushes the rocket forward.

There are several types of rocket propulsion systems:

Type	Uses	Advantages	Disadvantages
Solid fuel chemical propulsion	main booster	simple, reliable, few moving parts, lots of thrust	not restartable
Liquid fuel chemical propulsion	main booster, small control	restartable, controllable, lots of thrust	complex
Cold-gas chemical propulsion	small control	restartable, controllable	low thrust
Ion	in space booster	restartable, controllable, high specific impulse	complex

The solid motor is used mainly as a booster for launch vehicles. Solid motors are almost never used in space because they are not controllable. The boosters are lit and then they fire until all the propellant has burned. Their main benefits are simplicity, a shelf life which can extend to years as in the case of missiles, and high reliability.

Liquid motors come in many shapes and sizes: Most of them are controllable (can be throttled up and down), restartable, are often used as control and maneuvering thrusters. Liquid thrusters can be broken into three main types: monopropellant, bipropellant, and cryogenic thrusters. Monopropellants only use one propellant such as hydrazine. Bipropellants use a fuel and an oxidizer such as RP-1 and H2O2. Cryogenic systems use liquefied gases such as LiH and LOX (liquid hydrogen and liquid oxygen). Cryogenic means super-cooled. You would have to super-cool hydrogen and oxygen to make them liquids. With each step from monopropellant to bipropellant to cryogenic the thruster complexity goes up but the performance also goes up.

Cold-gas motors have controllability similar to liquids but are the simpler and lighter. They are basically a high pressure tank with switches which flip between the open and shut state. They function a little like spray paint, with the contents under pressure inside, and when the valve is opened, they stream out.

Ion engines are vastly different from chemical (solid, liquid) engines in that they are low thrust engines which can run for extended periods of time. The length of use of chemical engines is usually from seconds to days while the

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length of use of ion engines can be anywhere from days to months.

IV. OPERATION

The action of the rocket engine's combustion chambers and expansion nozzles on a high pressure fluid is able to accelerate the fluid to extremely high speed, and conversely this exerts a large reactive thrust on the rocket (an equal and opposite reaction according to Newton's third law), which propels the rocket forwards. Care is needed in determining where exactly the reactive thrust acts and it is often mislocated.

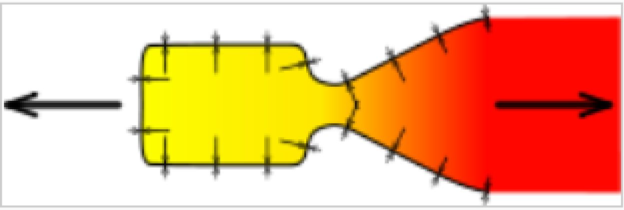

Fig:3 Rocket thrust is caused by pressures acting on both the combustion chamber and nozzle

In a closed chamber, the pressures are equal in each direction and no acceleration occurs. If an opening is provided in the bottom of the chamber then the pressure is no longer acting on the missing section. This opening permits the exhaust to escape. The remaining pressures give a resultant thrust on the side opposite the opening, and these pressures are what push the rocket along.

The shape of the nozzle is important. Consider a balloon propelled by air coming out of a tapering nozzle. In such a case the combination of air pressure and viscous friction is such that the nozzle does not push the balloon but is pulled by it. Using a convergent/divergent nozzle gives more force since the exhaust also presses on it as it expands outwards, roughly doubling the total force. If propellant gas is continuously added to the chamber then these pressures can be maintained for as long as propellant remains. Note that the pumps moving the propellant into the combustion chamber must maintain a pressure larger than the combustion chamber -typically on the order of 100 atmospheres.

As a side effect, these pressures on the rocket also act on the exhaust in the opposite direction and accelerate this exhaust to very high speeds (according to Newton's Third Law). From the principle of conservation of momentum the speed of the exhaust of a rocket determines how much momentum increase is created for a given amount of propellant. This is called the rocket's specific impulse. Because a rocket, propellant and exhaust in flight, without any external perturbations, may be considered as a closed system, the total momentum is always constant. Therefore, the faster the net speed of the exhaust in one direction, the greater the speed of the rocket can achieve in the opposite direction. This is especially true since the rocket body's mass is typically far lower than the final total exhaust mass.

V. NEWTON'S LAW OF INERTIA

Newton's first law states that every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force. This is normally taken as the definition of inertia. The key point here is that if there is no net force acting on an object (if all the external forces cancel each other out) then the object will maintain a constant velocity. If that velocity is zero, then the object remains at rest. And if an additional external force is applied, the velocity will change because of the force.

Newton's second law of motion pertains to the behavior of objects for which all existing forces are not balanced. The second law states that the acceleration of an object is dependent upon two variables - the net force acting upon the object and the mass of the object. The acceleration of an object depends directly upon the net force acting upon the object, and inversely upon the mass of the object. As the force acting upon an object is increased, the acceleration of the object is increased. As the mass of an object is increased, the acceleration of the object is decreased.

Newton's second law of motion can be formally stated as follows:

The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

This verbal statement can be expressed in equation form as follows:

$a = F_{net} / m$

The above equation is often rearranged to a more familiar form as shown below. The net force is equated to the product of the mass times the acceleration.

$F_{net} = m \cdot a$

The acceleration is directly proportional to the net force; the net force equals mass times acceleration; the acceleration in the same direction as the net force; an acceleration is produced by a net force.

VI. FORCES ON A ROCKET

The general study of the forces on a rocket is part of the field of ballistics.

Forces on a rocket in flight, rockets that must travel through the air are usually tall and thin as this shape gives a high ballistic coefficient and minimizes drag losses.

Just prior to engine ignition, the velocity of the rocket is zero and the rocket is at rest. If the rocket is sitting on its fins, the weight of the rocket is balanced by the re-action of the earth to the weight as described by Newton's third law of motion. There is no net force on the object, and the rocket would remain at rest indefinitely.

When the engine is ignited, the thrust of the engine creates an additional force opposed to the weight. As long as the thrust is less than the weight, the combination of the thrust and the re-action force through the fins balance the weight and there is no net external force and the rocket stays on the pad. When the thrust is equal to the weight, there is no longer any re-action force through the fins, but the net force on the rocket is still zero. When the thrust is greater than the weight, there is a net external force equal to the thrust minus the weight, and the rocket begins to rise.

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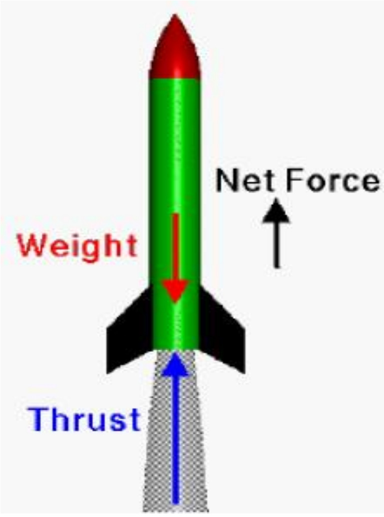

Fig:4 Newton's First Law applied to Rocket

The velocity of the rocket increases from zero to some positive value under the acceleration produced by the net external force. But as the rocket velocity increases, it encounters air resistance, or drag, which opposes the motion and increases as the square of the velocity. The thrust of the rocket must be greater than the weight plus the drag for the rocket to continue accelerating. If the thrust becomes equal to the weight plus the drag, the rocket will continue to climb at a fixed velocity, but it will not accelerate.

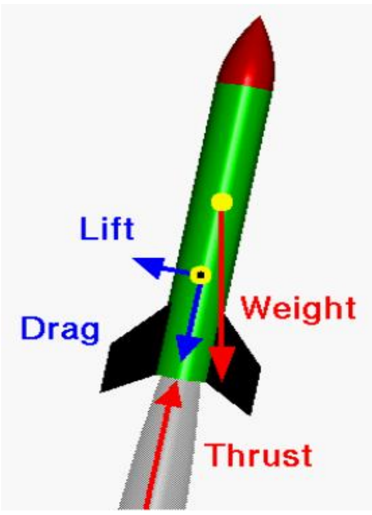

Fig:5 Forces of a Rocket

Flying rockets are primarily affected by the following:

- Thrust from the engine(s)
- Gravity from celestial bodies
- Drag if moving in atmosphere
- Lift; usually relatively small effect except for rocket-powered aircraft

Forces are vector quantities having both a magnitude and a direction. When describing the action of forces, one must account for both the magnitude and the direction. In flight, a rocket is subjected to four forces; weight, thrust, and the aerodynamic forces, lift and drag. The magnitude of the weight depends on the mass of all of the parts of the rocket. The weight force is always directed towards the center of the earth and acts through the center of gravity, the yellow dot on the figure. The magnitude of the thrust depends on the mass flow rate through the engine and the velocity and pressure at the exit of the nozzle. The thrust force normally acts along the longitudinal axis of the rocket and therefore acts through the center of gravity. Some full scale rockets can move, or gimbal, their nozzles to produce a force which is not aligned with the center of gravity. The resulting torque about the center of gravity can be used to maneuver the rocket. The magnitude of the aerodynamic forces depends on the shape, size, and velocity of the rocket and on properties of the atmosphere. The aerodynamic forces act through the center of pressure, the black and yellow dot on the figure. Aerodynamic forces are very important for model rockets, but may not be as important for full scale rockets, depending on the mission of the rocket. Full scale boosters usually spend only a short amount of time in the atmosphere.

In flight the magnitude, and sometimes the direction, of the four forces is constantly changing. The response of the rocket depends on the relative magnitude and direction of the forces. If we add up the forces, being careful to account for the direction, we obtain a net external force on the rocket. The resulting motion of the rocket is described by Newton's laws of motion.

In addition, the inertia and centrifugal pseudo-force can be significant due to the path of the rocket around the center of a celestial body; when high enough speeds in the right direction and altitude are achieved a stable orbit or escape velocity is obtained.

These forces, with a stabilizing tail (the empennage) present will, unless deliberate control efforts are made, naturally cause the vehicle to follow a roughly parabolic trajectory termed a gravity turn, and this trajectory is often used at least during the initial part of a launch.

A. Rocket Weight Equation

Weight is the force generated by the gravitational attraction on the rocket. Weight is fundamentally different from the aerodynamic forces, lift and drag. Aerodynamic forces are mechanical forces and the vehicle has to be in physical contact with the air which generates the force. The aerodynamic forces, lift and drag, and the thrust force are mechanical forces. The rocket must be in physical contact with the gases which generates these forces. The gravitational force is a field force and the rocket does not have to be in contact with the source of this force.

The gravitational force, F, between two particles equals a universal constant, G, times the product of the mass of the particles, m1 and m2, divided by the square of the distance, d, between the particles.

F = G * m1 * m2 / d^2

In general: $F = G \frac{m_1 m_2}{d^2}$

Force equals a gravitational constant times the product of the masses divided by the square of the distance between the masses.

$$g = G \frac{m_{earth}}{d^2_{earth}} = 9.8 \frac{meter}{sec^2} = 32.2 \frac{feet}{sec^2}$$

$$W = m \ g$$

Weight equals mass times gravitational acceleration.

Fig:6 Weight Equation

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For objects near the Earth, the sum of the mass of all the particles is simply the mass of the Earth and the distance is then measured from the center of the Earth. On the surface of the Earth the distance is about 4000 miles. Scientists have combined the universal gravitational constant, the mass of the Earth, and the square of the radius of the Earth to form the Earth's gravitational acceleration, ge .

ge = G * m Earth / (d Earth)^2
ge = 9.8 m/sec^2 = 32.2 ft/sec^2

The weight W, or gravitational force, is then just the mass of an object times the gravitational acceleration.

W = m * ge

An object's mass does not change from place to place, but an object's weight does change because the gravitational acceleration ge depends on the square of the distance from the center of the Earth. Let's do a calculation and determine the weight of the Space Shuttle in low Earth orbit. On the ground, the orbiter weighs about 250,000 pounds. In orbit, the Shuttle is about 200 miles above the surface of the Earth; the distance from the center of the Earth is 4200 miles. Then:

m = Ws / ge = Wo / go
Wo = Ws * go / ge

Where Ws = surface weight (250,000 pounds), Wo is the orbital weight, and go is the orbital value of the gravitational acceleration. We can calculate the ratio of the orbital gravitational acceleration to the value at the surface of the Earth as the square of Earth radius divided by the square of the orbital radius.

go / ge = (d Earth)^2 / (d orbit)^2
go / ge = (4000/4200)^2 = .907

On orbit, the shuttle weighs 250,000 * .907 = 226,757 pounds. Notice: the weight is not zero. There is a large gravitational force acting on the Shuttle at a distance of 200 miles. The "weightlessness" experienced by astronauts on board the Shuttle is caused by the free-fall of all objects in orbit. The Shuttle is pulled towards the Earth because of gravity. But the high orbital speed, tangent to the surface of the Earth, causes the fall towards the surface to be exactly matched by the curvature of the Earth away from the shuttle. In essence, the shuttle is constantly falling all around the Earth.

Because the weight of an object depends on the mass of the object, the mass of the attracting object, and the square of the distance between them, the surface weight of an object varies from planet to planet. We have derived a gravitational acceleration for the surface of the Earth, ge = 9.8 m/sec^2, based on the mass of the Earth and the radius of the Earth. There are similar gravitational accelerations for every object in the solar system which depend on the mass of the object and the radius of the object. Of particular interest for the Vision for Space Exploration, the gravitational acceleration of the Moon gm is given by:

gm = G * m Moon / (d Moon)^2
gm = 1.61 m/sec^2 = 5.3 ft/sec^2

and the gravitational acceleration of Mars gmar is given by:

gmar = G * m Mars / (d Mars)^2
gmar = 3.68 m/sec^2 = 12.1 ft/sec^2

The mass of a rocket is the same on the surface of the Earth, the Moon and Mars. But on the surface of the Moon, the weight force is approximately 1/6 the weight on Earth, and on Mars, the weight is approximately 1/3 the weight on Earth. You don't need as much thrust to launch the same rocket from the Moon or Mars, because the weight is less on these planets.

All forces are vector quantities having both a magnitude and a direction. For a rocket, weight is a force which is always directed towards the center of the Earth. The magnitude of this force depends on the mass of all of the parts of the rocket itself, plus the amount of fuel, plus any payload on board. The weight is distributed throughout the rocket, but we can often think of it as collected and acting through a single point called the center of gravity. In flight, the rocket rotates about the center of gravity, but the direction of the weight force always remains toward the center of the Earth.

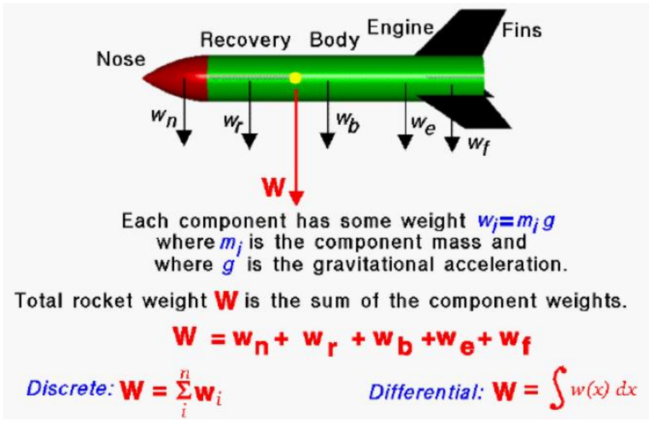

Fig:7 Determining Rocket Weight

During launch the rocket burns up and exhausts its fuel, so the weight of the rocket constantly changes. For a model rocket, the change is a small percentage of the total weight and we can determine the rocket weight as the sum of the component weights. For a full scale rocket, the change is large and must be included in the equations of motion. Engineers have established several mass ratios which help to characterize the performance of a rocket with changing mass. Full scale rockets are often staged or broken into smaller rockets which are discarded during flight to increase the rocket's performance.

B. Rocket Thrust Equation

Thrust is the force which moves the rocket through the air, and through space. Thrust is generated by the propulsion system of the rocket through the application of Newton's third law of motion; for every action there is an equal and opposite re-action. In the propulsion system, an engine does work on a gas or liquid, called a working fluid, and accelerates the working fluid through the propulsion system. The re-action to the acceleration of the working fluid produces the thrust force

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on the engine. The working fluid is expelled from the engine in one direction and the thrust force is applied to the engine in the opposite direction.

The direction of the thrust is normally along the longitudinal axis of the rocket through the rocket center of gravity. The magnitude of the thrust can be determined by the general thrust equation. The magnitude of the thrust depends on the mass flow rate of the working fluid through the engine and the exit velocity and pressure of the working fluid. The efficiency of the propulsion system is characterized by the specific impulse; the ratio of the amount of thrust produced to the weight flow of the propellants.

All rocket engines produce thrust by accelerating a working fluid. But there are many different ways to produce the acceleration, and many different available working fluids.

In a rocket, stored fuel and stored oxidizer are pumped into a combustion chamber where they are mixed and exploded. The hot exhaust is then passed through a nozzle, which accelerates the flow. The exit velocity is determined by the shape of the rocket nozzle and is supersonic. The exit pressure is set by the nozzle shape as well and will only be equal to free stream pressure at some design condition. Thrust equation is used to describe the thrust of the system

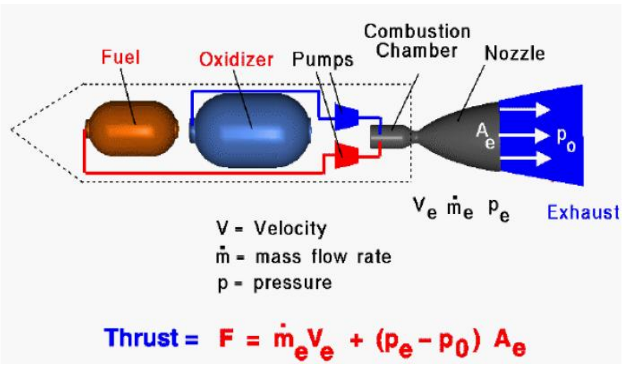

Fig:8 Thrust Equation

The amount of thrust produced by the rocket depends on the mass flow rate through the engine, the exit velocity of the exhaust, and the pressure at the nozzle exit. All of these variables depend on the design of the nozzle. The smallest cross-sectional area of the nozzle is called the throat of the nozzle.

This thrust equation works for both liquid and solid rocket engines. The mass flow rate through the propulsion system is determined by the nozzle design. There is no free stream mass times free stream velocity term in the thrust equation because no external air is brought on board. Since the oxidizer is carried on board the rocket, rockets can generate thrust in a vacuum where there is no other source of oxygen. That's why a rocket will work in space, where there is no surrounding air, and a gas turbine or propeller will not work. There is also an efficiency parameter called the specific impulse which works for both types of rockets and greatly simplifies the performance analysis for rockets.

C. Aerodynamic Forces

When a solid body is moved through a fluid (gas or liquid), the fluid resists the motion. The object is subjected to an aerodynamic force in a direction opposed to the motion which we call drag. Geometry has a large effect on the aerodynamic forces generated by an object. Lift and drag depend linearly on the size of the object moving through the air.

If we think of drag as aerodynamic friction, the amount of drag depends on the surface roughness of the object; a smooth, waxed surface produces less drag than a roughened surface. This effect is called skin friction and is usually included in the measured drag coefficient of the object. Lift and drag are associated with the movement of the rocket through the air, so lift and drag depend on the velocity of the air. Lift and drag actually vary with the square of the relative velocity between the object and the air.

Lift and drag depend directly on the mass of the flow going past the rocket. The drag also depends in a complex way on two other properties of the air: its viscosity and its compressibility.

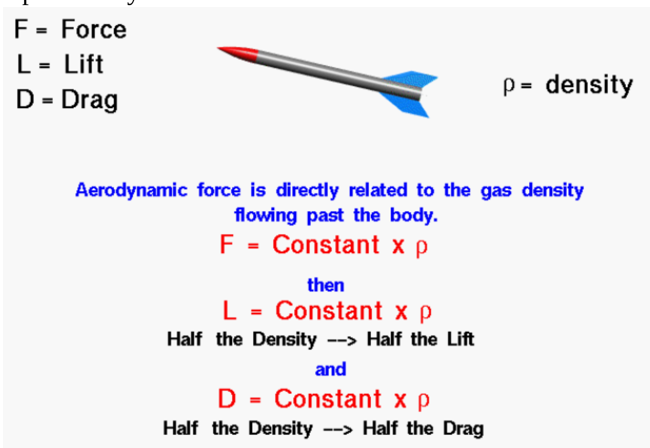

Fig: 9 Density affects on Aerodynamic Force

The aerodynamic force equals a constant times the density times the velocity squared. The dynamic pressure of a moving flow is equal to one half of the density times the velocity squared. Therefore, the aerodynamic force is directly proportional to the dynamic pressure q of the flow.

$$F = \text{constant} * q$$

Where the value of this constant is different than the previous constant. Lift and drag depend linearly on the density of the fluid. Halving the density halves the lift, halving the density halves the drag. The fluid density depends on the type of fluid and the depth of the fluid. In the atmosphere, air density decreases as altitude increases.

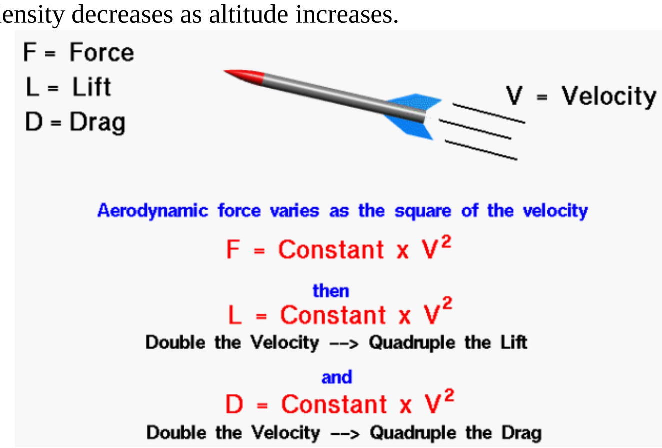

Fig:10 Velocity Effects on Aerodynamic Force

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The aerodynamic force equals a constant times the density times the velocity squared. The dynamic pressure of a moving flow is equal to one half of the density times the velocity squared. Therefore, the aerodynamic force is directly proportional to the dynamic pressure of the flow.

The velocity used in the lift and drag equations is the relative velocity between an object and the flow. Since the aerodynamic force depends on the square of the velocity, doubling the velocity will quadruple the lift and drag.

The amount of drag generated by an object depends on the size of the object. Drag is an aerodynamic force and therefore depends on the pressure variation of the air around the body as it moves through the air. The total aerodynamic force is equal to the pressure times the surface area around the body. Drag is the component of this force along the flight direction. Like the other aerodynamic force, lift, the drag is directly proportional to the area of the object. Doubling the area doubles the drag.

D. *The Drag Equation*

Drag depends on the density of the air, the square of the velocity, the air's viscosity and compressibility, the size and shape of the body, and the body's inclination to the flow. In general, the dependence on body shape, inclination, air viscosity, and compressibility is very complex.

$$D = Cd \frac{\rho V^2}{2} A$$

Drag = coefficient x density x $\frac{\text{velocity squared}}{\text{two}}$ x reference area

Coefficient Cd contains all the complex dependencies and is usually determined experimentally.

Choice of reference area A affects the value of Cd.

Fig:11 The Drag Equation

The drag equation states that drag D is equal to the drag coefficient Cd times the density r times half of the velocity V squared times the reference area A.

The drag coefficient is a number that engineers use to model all of the complex dependencies of shape and flow conditions on rocket drag. This equation is simply a rearrangement of the drag equation where we solve for the drag coefficient in terms of the other variables. The drag coefficient Cd is equal to the drag D divided by the quantity: density r times half the velocity V squared times the reference area A.

$$Cd = \frac{D}{\rho V^2 A / 2}$$

Coefficient Cd contains all the complex dependencies and is usually determined experimentally.

Choice of reference area A affects the value of Cd.

Fig:12 The Drag Coefficient

The drag coefficient contains not only the complex dependencies of object shape, but also the effects of air viscosity and compressibility.

E. *The Lift Equation*

Lift depends on the density of the air, the square of the velocity, the air's viscosity and compressibility, the surface area over which the air flows, the shape of the body, and the body's inclination to the flow. In general, the dependence on body shape, inclination, air viscosity, and compressibility is very complex.

$$L = Cl \frac{\rho V^2}{2} A$$

Lift = coefficient x $\frac{\text{density x velocity squared}}{\text{two}}$ x wing area

Coefficient Cl contains all the complex dependencies and is usually determined experimentally.

Fig: 13The Lift Equation

The lift equation states that lift L is equal to the lift coefficient Cl times the density r times half of the velocity V squared times the wing area A.

The lift coefficient is a number that engineers use to model all of the complex dependencies of shape, inclination, and some flow conditions on lift. This equation is simply a rearrangement of the lift equation where we solve for the lift coefficient in terms of the other variables. The lift coefficient Cl is equal to the lift L divided by the quantity: density r times half the velocity V squared times the wing area A.

$$Cl = \frac{L}{\rho V^2 A / 2}$$

Cl contains all the complex dependencies and is usually determined experimentally.

Fig:14 The Lift Coefficient

The lift coefficient contains the complex dependencies of object shape on lift. The lift coefficient also contains the effects of air viscosity and compressibility.

F. *Energy Efficiency*

The energy density of a typical rocket propellant is often around one-third that of conventional hydrocarbon fuels; the bulk of the mass is (often relatively inexpensive) oxidizer.

Energy from the fuel is lost in air drag and gravity drag and is used for the rocket to gain altitude and speed. However, much of the lost energy ends up in the exhaust.

In a chemical propulsion device, the engine efficiency is simply the ratio of the kinetic power of the exhaust gases and the power available from the chemical reaction:

$$\eta_c = \frac{\frac{1}{2}\dot{m}v_e^2}{\eta_{combustion} P_{chem}}$$

100% efficiency within the engine (engine efficiency

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$\eta_c = 100\%$) would mean that all the heat energy of the combustion products is converted into kinetic energy of the jet.

The high efficiency is a consequence of the fact that rocket combustion can be performed at very high temperatures and the gas is finally released at much lower temperatures, and so giving good Carnot efficiency.

In common with the other jet-based engines, but particularly in rockets due to their high and typically fixed exhaust speeds, rocket vehicles are extremely inefficient at low speeds irrespective of the engine efficiency. The problem is that at low speeds, the exhaust carries away a huge amount of kinetic energy rearward. This phenomenon is termed propulsive efficiency (η_p).

G. Oberth Effect

One subtle feature of rockets relates to energy. A rocket stage, while carrying a given load, is capable of giving a particular delta-v. This delta-v means that the speed increases (or decreases) by a particular amount, independent of the initial speed. However, because kinetic energy is a square law on speed, this means that the faster the rocket is travelling before the burn the more orbital energy it gains or loses.

This fact is used in interplanetary travel. It means that the amount of delta-v to reach other planets, over and above that to reach escape velocity can be much less if the delta-v is applied when the rocket is travelling at high speeds, close to the Earth or other planetary surface; whereas waiting until the rocket has slowed at altitude multiplies up the effort required to achieve the desired trajectory.

VII. CONCLUSION

It is found that it's hard to change the motion of an object that has lots of inertia and it's easy to change the motion of an object that has little inertia. Mass is the measure of object's inertia. Objects with little inertia have a small mass and objects with lot of inertia have large mass.

If the forces applied to the object cancel each other out, the object is not going to accelerate. Newton’s laws of inertia have helped us to understand the net force of rocket namely thrust, weight, lift and drag.

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