Rocket Propulsion

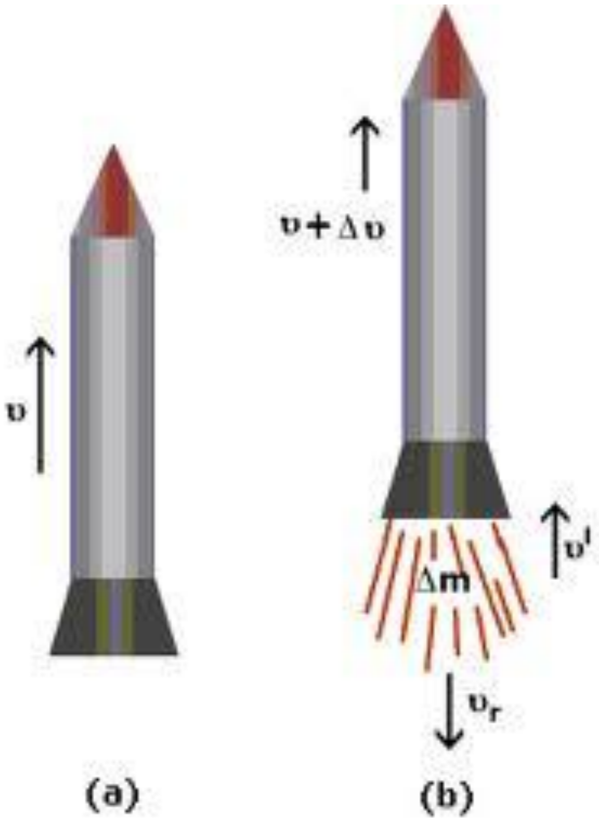
Dr. GUVEN
Aerospace Engineer (P.hD)
Nuclear Rocket Propulsion Specialist
Nuclear Science and Technology Engineer (M.Sc)

Phases of Propulsion

- When we talk about the aspects of rocket propulsion, we are actually talking about two phases of rocket propulsion
- The first phase is Take Off / Launch of Spacecraft
- The second phase is maneuverability in near Earth space
- The third phase is Deep Space Propulsion for faraway targets

Types of Propulsion

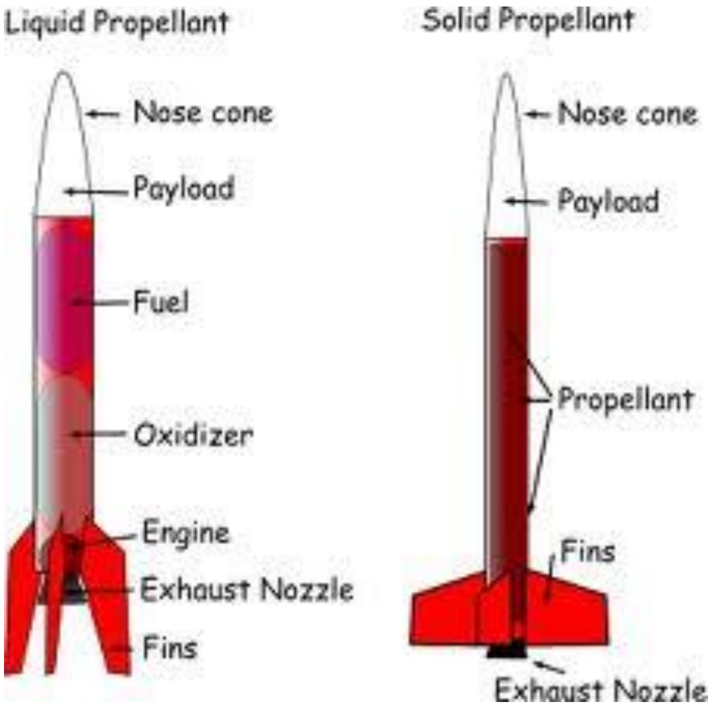
- Chemical Propulsion
- Nuclear Propulsion
- Ion Propulsion
- Solar Propulsion
- Gravity Propulsion
- Futuristic Propulsion Methods

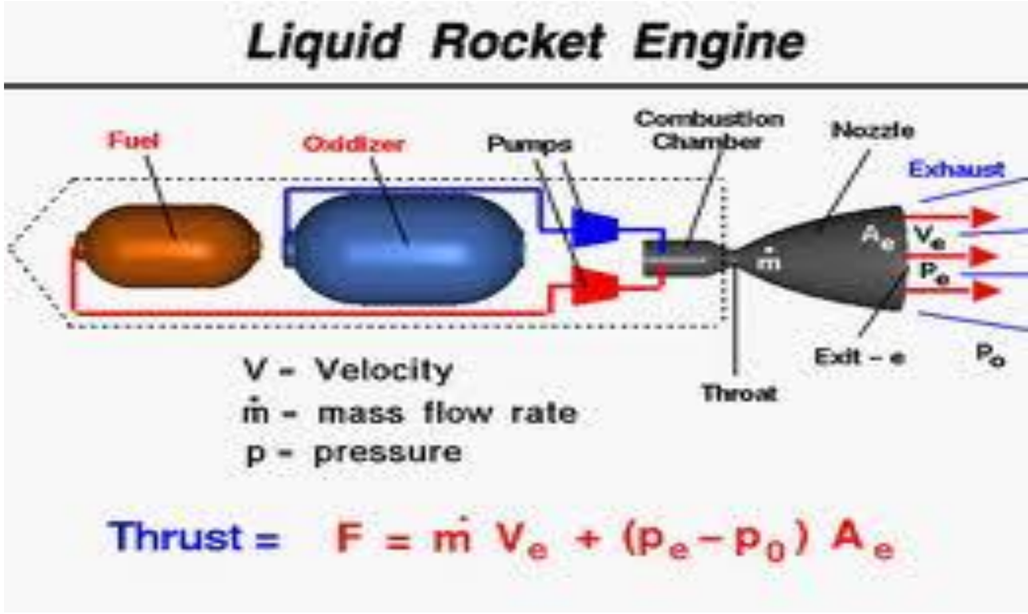


Rocket propulsion

Types of Propellants

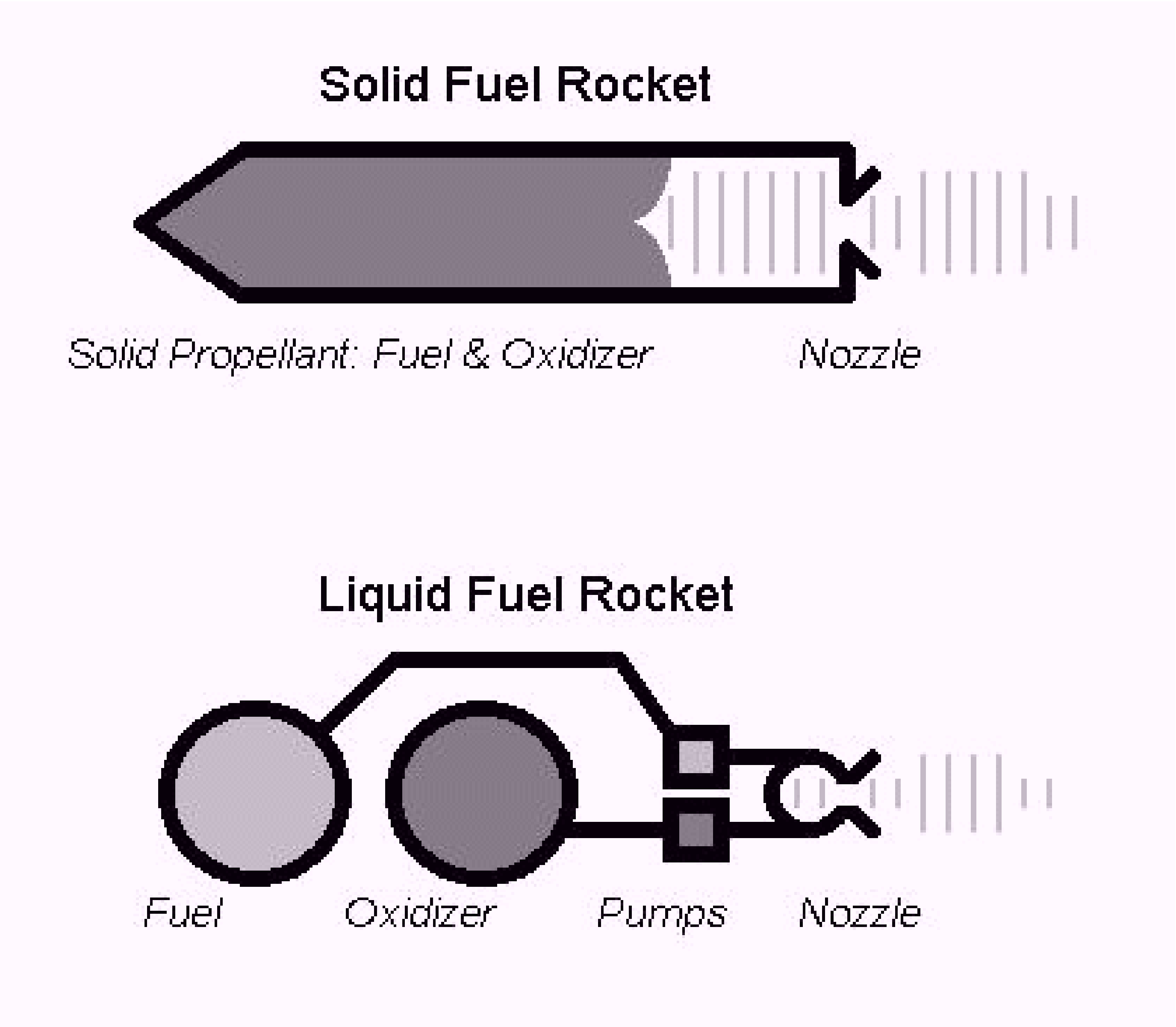
- Solid Propellants
- Liquid Propellants





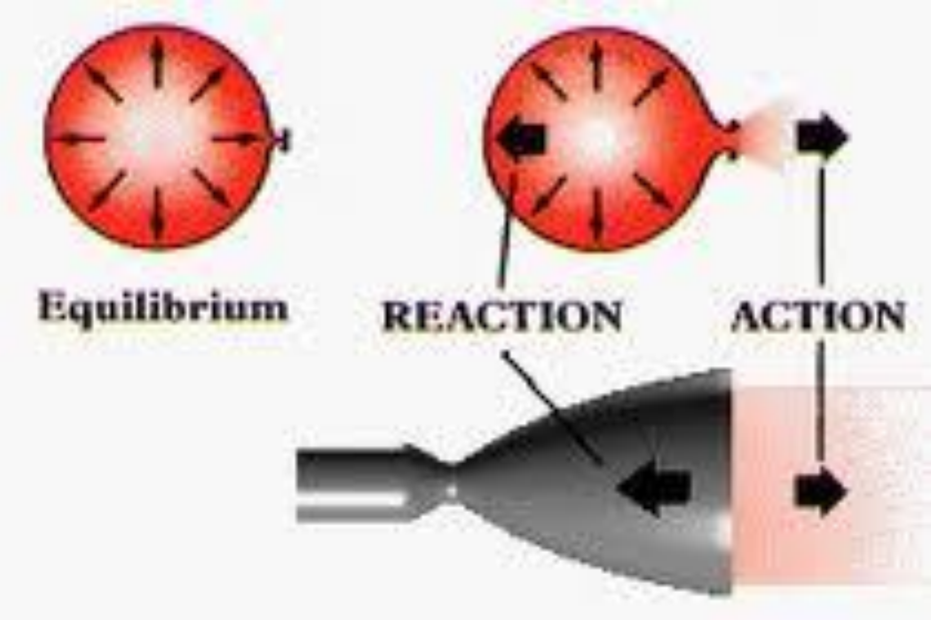
- Gas Propellants
- Plasma Propellants

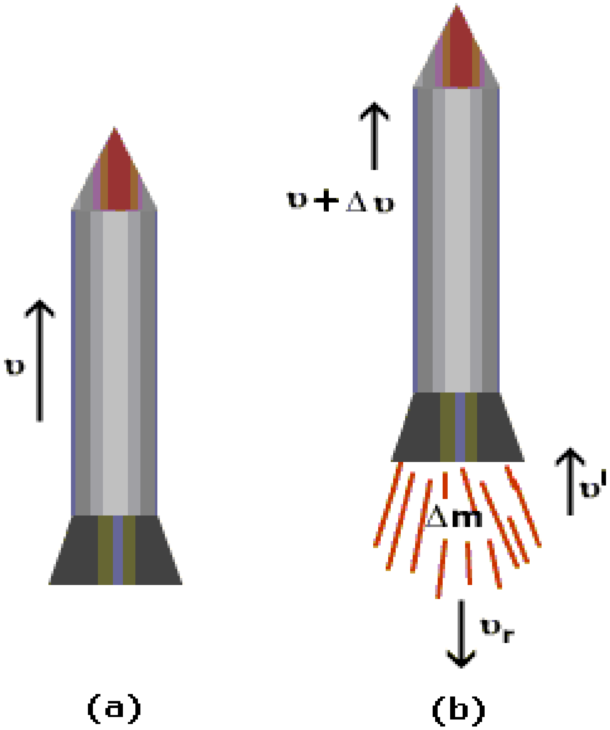
Solid / Liquid Propellant



How Does a Rocket Propel?

- The rocket’s propulsion is governed by Newton’s equations. In essence, it is creating backward thrust in one direction and as a result, the rocket will create forward thrust in the reverse direction due to Newton’s Laws





Rocket propulsion

Propulsion Terminology

- To launch a rocket or to move a rocket through space, we must use a propulsion system to generate thrust. Thrust is generated through an application of Newton's third law of motion; a working gas is accelerated to the rear of the rocket engine, and the re-action is a thrust force applied to the engine in the forward direction.
- In solid and liquid fueled rocket engines, the working gas is produced through the burning of a fuel to produce power. Burning a fuel is called **combustion**

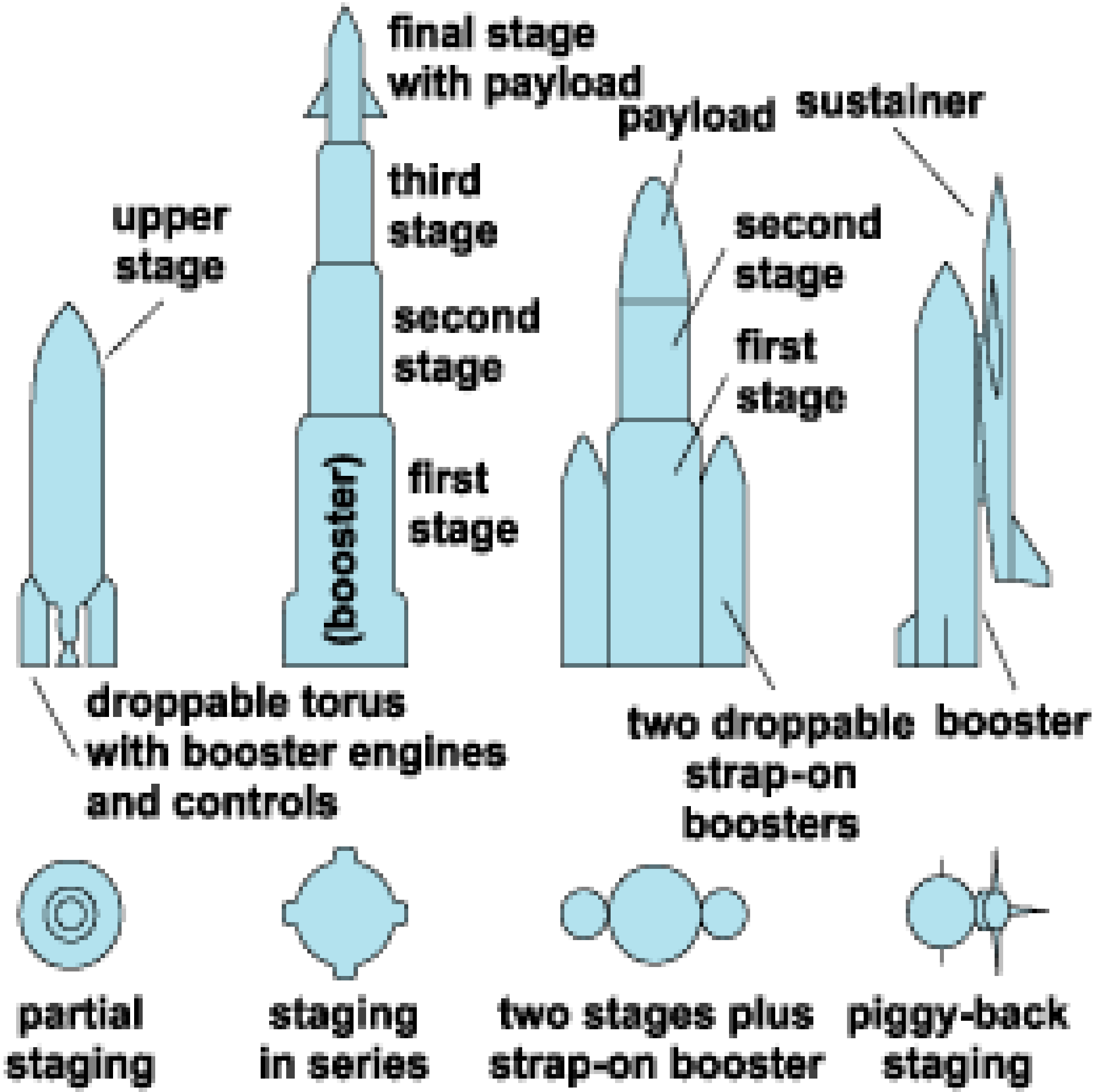
Combustion

- **Combustion** is a chemical process in which a substance reacts rapidly with oxygen and gives off heat. The original substance is called the **fuel,** and the source of oxygen is called the **oxidizer**. The fuel and oxidizer can be a solid, liquid, or gas. For rocket propulsion the fuel and oxidizer are usually stored as either a liquid or a solid.

Exhaust

- During combustion, new chemical substances are created from the fuel and the oxidizer. These substances are called **exhaust**. Most of the exhaust comes from chemical combinations of the fuel and oxygen. When a hydrogen-carbon-based fuel (like gasoline) burns, the exhaust includes water (hydrogen + oxygen) and carbon dioxide (carbon + oxygen).

Stages of a Rocket

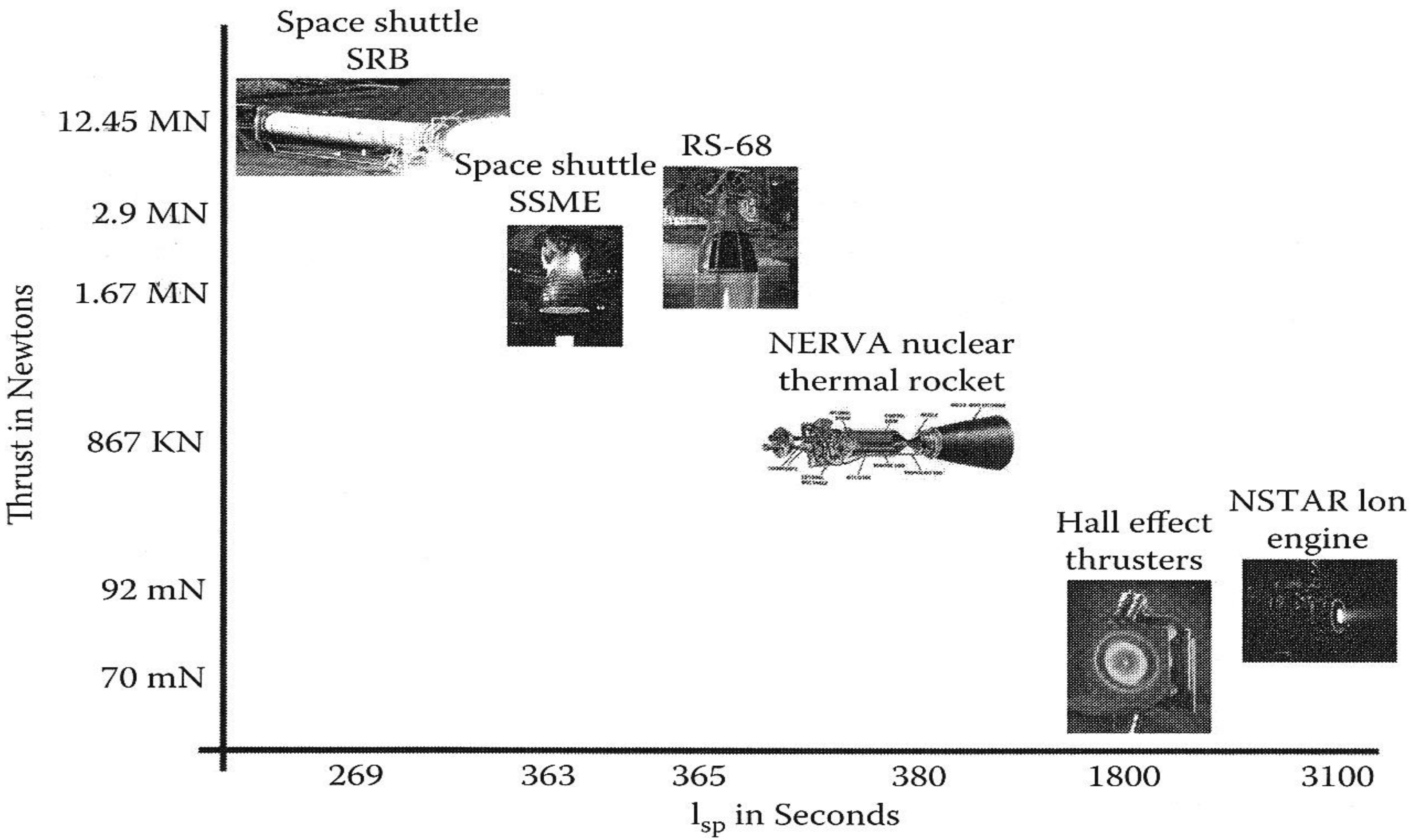


Specific Impulse

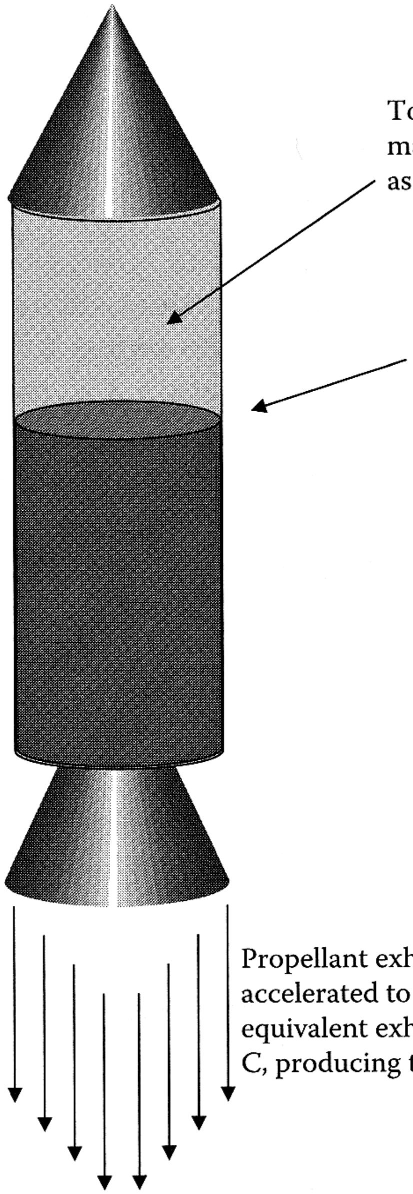
- One of the best ways to analyze rocket’s performance in terms of propulsion would be specific impulse.
- With specific impulse, we will have an idea of the rocket’s overall capability in terms of speed and in terms of range

$$I_{sp} = \frac{V_e}{g} = \frac{F}{\dot{m}g}$$

Specific Impulse of Spacecraft



Rocket Thrust



Total rocket
mass M changes
as fuel is burned

Propellant is burned at
a rate of $\dot{m}$

Propellant exhaust is
accelerated to an
equivalent exhaust velocity,
C, producing thrust

$$F = \dot{m} \cdot V_e$$

Tsiolkovsky Equation

- From the Newton's equations of motion and momentum:

  Since Thrust is defined as :

$$F = ma = m\frac{dv}{dt} \qquad F = \dot{m} \cdot V_e$$

Thus by equating these two equations:

$$m\frac{dv}{dt} = -\frac{dm}{dt}V_e$$

Tsiolkovsky's Rocket Equation is born:

$$\Delta V = V_{exhaust} \ln \frac{M_{initial}}{M_{final}}$$

Calculation of Rocket Parameters

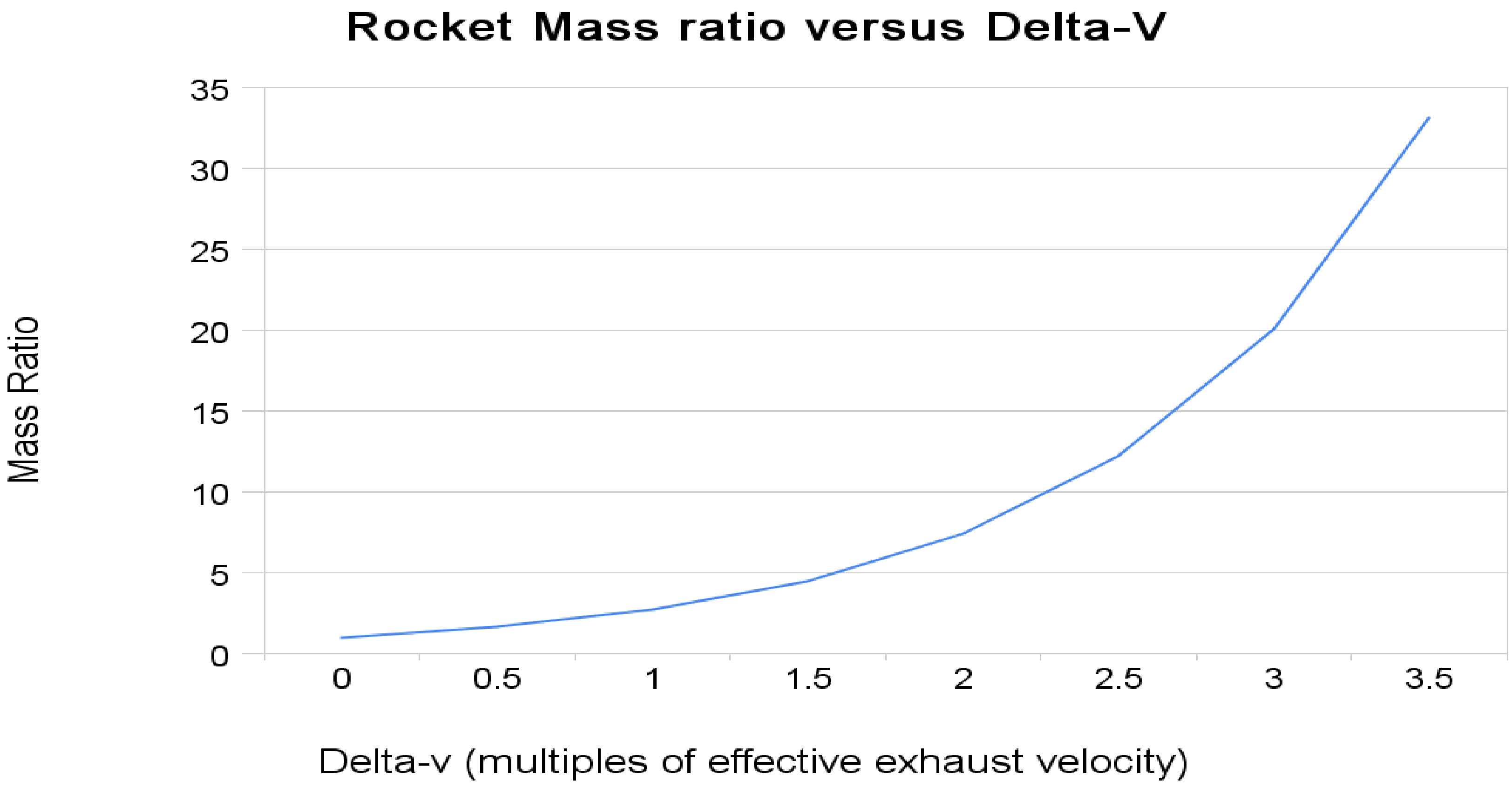
- If the space shuttle is used as an example, the parameters of its operation can be found by using the equations given above.
- The Space Shuttle has a specific impulse of 363 seconds at sea level. It is possible to calculate the Space Shuttle's effective exhaust velocity as well as its mass propellant rate as follows:
- Ve = 3557.4 m/sec *from*
- F = 1.8 x 10^6 N *from*
- m = 505.99 kg/sec *from*

$$I_{sp} = \frac{V_e}{g}$$

$$F = \dot{m} \cdot V_e$$

Rocket Mass Ratio

- Tsiolkovsky Equation clearly showed that mass ratio of spacecraft is determinant of the final velocity. You can effect the exhaust velocity by changing the mass ratio.



Rocket Performance

- In order to get a higher rocket speed performance (Delta V),
- a) The spacecraft needs to have either a very large ***Ve*** (exhaust gas velocity) or
- b) The spacecraft will need to have a very high proportion of ***m/mo***

Increasing Performance Through Fuel

- You can increase the rocket performance by increasing the amount of fuel in the spacecraft and hence by effecting m / mo

m/mo	Fuel %
5	80
6	83.3
7	86
8	87.5
9	89.2
10	90
15	93
20	95
30	97

Increasing Performance Through Exhaust Velocity

- Increasing the exhaust velocity will increase both the specific impulse as well as the delta v of a rocket.
- Exhaust velocity is mainly dependent on the temperature of the combustion.
- As gases (propellant) become s hotter, the molecules speed up. As a result hotter combustion causes gases to be discharged faster from the exhaust, thus causing a faster exhaust velocity

Increasing Thrust

- To create high speed exhaust gases, the necessary high temperatures and pressures of combustion are obtained by using a very energetic fuel and by having the molecular weight of the exhaust gases as low as possible.
- It is also necessary to reduce the pressure of the gas as much as possible inside the nozzle by creating a large section ratio. The section ratio, or expansion ratio, is defined as the area of the exit A_e divided by the area of the throat A_t.

Basic Thrust Equation

$$F = qV_e + (P_e - P_a)A_e$$

- Where q is the rate of the ejected mass flow, V_e is the exhaust gas ejection speed, P_e is the pressure of the exhaust gases at the nozzle exit, P_a is the pressure of the ambient atmosphere, and A_e is the area of the nozzle exit.
- The product qV_e, is called the momentum, or velocity, thrust. The product $(P_e - P_a)A_e$, called the pressure thrust, is the result of unbalanced pressure forces at the nozzle exit. Maximum thrust occurs when $P_e = P_a$

Example 1

- A spacecraft's engine ejects mass at a rate of 30 kg/s with an exhaust velocity of 3,100 m/s. The pressure at the nozzle exit is 5 kPa and the exit area is 0.7 m^2. What is the thrust of the engine in a vacuum?
- Given: $q = 30$ kg/s
- $Ve = 3{,}100$ m/s
- $Ae = 0.7\ m^2$
- $Pe = 5$ kPa $= 5{,}000\ N/m^2$
- $Pa = 0$
- $F = q \times Ve + (Pe - Pa) \times Ae$ F =
- $F= 30 \times 3{,}100 + (5{,}000 - 0) \times 0.7$ F = **96,500 N**

Example 2

- With the same rocket problem above, imagine that the final mass of the rocket is 28,300 kg and the initial mass of the rocket is 30,000 kg with the exhaust velocity of 3100 m/s. Calculate the rate of velocity change in that interval?

$$\Delta V = V_{exhaust} \ln \frac{M_{initial}}{M_{final}}$$

- Hence:
- V = Ve × LN[Mi / (Mf)]
- Delta V = 3100 x ln (30,000/28,300)
- Delta V = 192 m/s

Example 3

- A spacecraft's dry mass is 75,000 kg and the effective exhaust gas velocity of its main engine is 3,100 m/s. How much propellant must be carried if the propulsion system is to produce a total v of 700 m/s?
- From the Tsiolkovsky Equation:

$$\Delta V = V_{exhaust} \ln \frac{M_{initial}}{M_{final}}$$

- M_f = 75,000 kg, V_e = 3,100 m/s , Delta V = 700 m/s
- $M_o = M_f \times e^{(DV / Ve)}$
- $Mo = 75{,}000 \times e^{(700 / 3{,}100)}$ Mo = 94,000 kg
- Propellant mass, Mp = Mo - Mf
- Mp = 94,000 - 75,000
- Mp = 19,000 kg

Example 4

- A rocket engine produces a thrust of 1,000 kN at sea level with a propellant flow rate of 400 kg/s. Calculate the specific impulse
- Given: F = 1,000,000 N
- m = 400 kg/s

$$I_{sp} = \frac{V_e}{g} = \frac{F}{\dot{m}g}$$

- $I_{sp} = F / (m \times g)$
- $I_{sp} = 1{,}000{,}000 / (400 \times 9.80665)$
- $I_{sp} = 255$ s (sea level)

Long Distance Propulsion

- Long distances would require high specific impulse and thus high exhaust velocity. Hence, more exotic forms of propulsion are needed such as nuclear propulsion or ion propulsion to achieve higher exhaust velocities

Destination	Jet	Rocket	Ray of Light
	600 miles/hour	**25,000 miles/hour**	**186,282 miles/hour**
	965 Kms/hour	**40,250 Kms/hour**	**299,792 Kms/hour**
Sun	17 years	5 months	8 minutes
Earth's Moon	15 days	9 hours	1 second
Mercury	9 years	3 months	4 minutes
Venus	5 years	1 month	2 minutes
Mars	7 years	2 months	3 minutes
Jupiter	70 years	2 years	33 minutes
Saturn	141 years	3 years	1 hour
Uranus	305 years	7 years	2 hours
Neptune	509 years	12 years	4 hours
Pluto[β]	506 years	12 years	4 hours
Proxima Centauri (closest star to Earth other than the sun.)			4 years
Center of the **Milky Way Galaxy**			27,000 years

THANK YOU

- You can download all of the PowerPoint presentations as well as educational videos and software related to Aerospace Engineering in my website at

www.aerospacelectures.com

drguven@live.com