

# Evolution in Propellant of the Rocket Engine

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**Abstract** Evolution of rocket engine had contributed global opportunity for human civilization on the base of expanding science and technology, artificial intelligence and economic expansion which have given us potential to explore the universe as well as solve the burning issue over population, scarcity of basics and industrial resources, global warming and most prominently safety of mother earth and mankind. Hence, collecting and studying the data of various engine's propellants and structures made till date to overcome various efficiency challenges, analyzing the current potential and challenges; and future visions with possible challenges is important, conducted as an spontaneous effort by NASA, ISRO, CNSA, Space-X and other space agencies. This theoretical research will help us to find scope, challenge and method to solve those chaos related to space engine's efficiency in multiple time frame. Historic data will give us a mind set about our past experience of solving restriction giving us general ideas to solve future probable problems in propellant or fuel and design of rocket engine. History of primitive engine initiated since 1794 in Thomas Mead's gas engine, Robert Street's combustion engine in 1794, Francois Isaac de Rivaz's electric spark followed by industrial utilization of Samuel Brown's engine in 1823. Subsequently, all had set a base for the first liquid propellant rocket engine of Robert Goddard's facilitated by Felix Wankel's piston-less eccentric rotary engine design triggering today's biggest space travel vision ultimately necessary for modern world in order to understand universe, and space exploration coupled with mass inter-stellar emigration. Hence, we shall discuss about the historic problems of space engine with their solution made till date, instantaneous situation and complication in space engine coupled with future vision and obstacles with their suitable solutions. For instance; the the factors responsible for the improvement of propellant efficiency,  $I_{sp}$  relations with  $v_e$ ,  $F_n$  produced giving us mass ratio and various issues variability with the propellant used to produce an exhaust impact. By the help of comparative study of various engine's propellant and design, we can figure out future space engine challenges and solution. Here, we shall also discuss the changes brought in structure of physically powered rocket (cold gas thruster, water rocket), chemically powered rocket (solid rocket, hybrid rocket, mono-propellant rocket, bi-propellant rocket, dual mode propulsion rocket, tri-propellant rocket, air-augmented rocket, turbo rocket, precool-ed jet engine/LACE, electrically powered (resistojet rocket, arc jet rocket, variable specific impulse magneto-plasma rocket, pulsed plasma thruster, ion propulsion system), thermal powered, solar thermal powered, beamed thermal powered, nuclear thermal powered (radioscope rocket, nuclear fission energy), nuclear propulsion powered (gas core reactor rocket, fission fragment rocket, fission sail, nuclear salt-water rocket, nuclear pulse propulsion, antimatter catalyzed nuclear pulse propulsion fusion energy, and antimatter rocket) due to properties of propellant used in combustion chamber.

**Keywords:** combustion engine, rotary engine, propellant efficiency, specific impulse, exhaust velocity, pulse propulsion, antimatter, nuclear energy, mono propellant

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## 1. Introduction

### 1.1. Background

The journey of modern science and technology form the Paleolithic stage till today's ultra era, rocket engine have played a prominent role in polishing the standard vision of future human civilization in multiple aspect, and the journey is still on for improvement in various associated dynamics followed by restriction like energy efficiency, economic aspect, mechanical challenges, practical issues as well as theoretical threshold for a current vision of

space travel shall be accomplished for limitless journey of space engine evolution. Comparative study of improvement made in space engine, the particular reason for such changes will help us to figure out solution for current and future challenges including propellant, injection, combustion chamber, nozzle for the optimal expansion, propellant efficiency, thrust vectoring, specific impulse, vacuum specific impulse ( $I_{sp}$ ), thrust to weight ratio, cooling, combustion instabilities, chugging, screening, exhaust noise, testing and safety.

We discuss and compare the design of historic and modern space engine in various basset of energy efficiency, fuel used, material used, combustion, economic approach, and environmental approach. Comparative

study of historic and modern space engine with multiple improvements made will further give us and vision or idea to develop more efficient space engine in order to solve present challenges followed by future challenges.

In the parallel vein, detailed data collection of propellants (reaction mass) used to obtain high speed repulsive jet fluid comparing both combustion and non-combustion chemical used in chambers followed by the physical or chemical or electrical or thermal power with its merits and demerits. However, the discussion in change in interior and exterior structure of the rocket is mandatory after the changes brought in the propellants for the efficiency and safety.

## 1.2. Modern Rocket Engine

A rocket engine uses stored rocket propellants as the reaction for forming a high-speed propulsive jet of fluid, usually high-temperature gas. Rocket engines are reaction engines, producing thrust by ejecting mass rearward, in accordance with Newton's third law establishing escape velocity against the gravity of planet or satellite. Most rocket engines use the combustion of reactive chemicals to supply the necessary energy, but non-combusting forms such as cold gas thrust-er and nuclear thermal rockets also exist. Vehicles propelled by rocket engines are commonly called rocket. Rocket vehicles carry their own oxidizer, unlike most combustion engines, so rocket engines can be used in a vacuum to propel spacecraft and ballistic missiles.

Compared to other types of jet engines, rocket engines are the lightest and have the highest thrust, but are the least propellant-efficient (they have the lowest specific impulse). The ideal exhaust is hydrogen, the lightest of all elements, but chemical rockets produce a mix of heavier species, reducing the exhaust velocity. Hence, its crystal clear that fuel combustion engine with oxidizer is a major part of a rocket engine deviating the performance or safety, and hence development of an alternative powerful light energy can be a great milestone in current scenario.

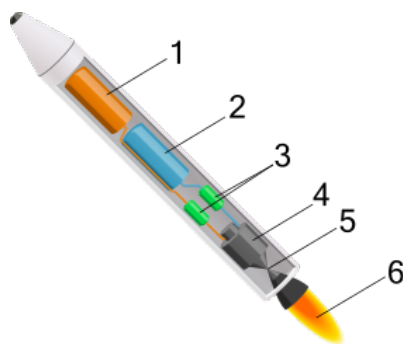


Figure 1.1. Simplified liquid-fuel rocket [1]

In figure, represented numbers identifies;

1. Liquid rocket fuel
2. Oxidizer
3. Pumps carry the fuel and oxidizer.
4. The combustion chamber mixes and burns the two liquids.
5. The hot exhaust is choked at the throat, which, among other things, dictates the amount of thrust produced.
6. Exhaust exits the rocket

Rocket engines produce thrust by the expulsion of an exhaust fluid that has been accelerated to high speed through a propelling nozzle. The fluid is usually a gas created by high pressure {150-to-4,350-pound-per-square-inch (10 to 300 bar)} combustion of solid or liquid propellants, consisting of fuel and oxidizer components, within a combustion chamber. As the gasses expand through the nozzle, they are accelerated to very high (supersonic) speed, and the reaction to this pushes the engine in the opposite direction. Till date, Combustion is most frequently used for practical rockets, as high temperatures and pressures are desirable for the best performance. Liquid rocket fuel tank, is the most prominent part of rocket engine which contains the propellant as main light chemical ingredient for the producing exhaust coupling with extreme temperature and pressure responsible for high thrust-mass ratio. Discussion of various chemicals used in this chamber with their comparative analysis throughout the rocket evolution timeline is a major priority. Following this chamber, secondly, oxidizer plays a prominent role to provide technically controlled combustion atmosphere for propellant within the rocket engine inside or outside the gravitation field of heavy space masses. The selection of oxidizer chemicals throughout the historic phase with their selection reason shall be done with all merits and demerits.

Meanwhile, two pumps individually carry the fuel and oxidizer towards the combustion chamber which mixes and burns the two liquids in the fuel tank and oxidizer. Here, the metal selected to make the combustion chamber is of huge chaos because it requires light in order to increase the rocket efficiency and extremely high temperature and pressure resistance for the safety of the rocket. For the additional safety, the use of an additional cooler is mandatory. Simultaneously, the hot exhaust is choked at the throat, which, among other things, dictates the amount of thrust produced based on the principle of Pascal's law. Finally the exhaust exits the rocket releasing the exhaust mass that passed from throat in extreme pressure against the gravitational pull of particular heavenly body's surface crossing the limit of it's escape velocity inside the gravitational field or controlled exhaust as required in space where there is absence of resultant gravitational field [2]. The various metals or alloy used to make exterior design or parts of the rocket throughout plays an important role in efficiency of the rocket which will be compared on the basis of variation brought in thrust mass ratio. In the vein of fuel tank, oxidizer tank, pump, combustion chamber and exhaust, similar analysis is a must. Lastly, chemicals used inside propellant tanks and oxidizer tanks have been changed or improved throughout the time; still even other better alternative energy systems are being searched, tested and required for the glorious future of space travel. Perhaps, now, the main part of this research shall be concentrated on figuring out various types of chemicals such as propellant fuel and oxidizer by different rocket engine models as well as the reason behind it. It can be done by calculating specific impulse/atmospheric specific impulse ( $I_{sp}$ ), total thrust of the rocket engine on the performance ( $F_n$ ), exhaust gas mass flow ( $\dot{m}$ ), effective exhaust velocity ( $v_e$ ), effective jet velocity when  $P_{amb}=P_e$  ( $v_{e-opt}$ ), flow are at

nozzle exit plane (or the plane where the jet leaves the nozzle if separated flow) ( $A_e$ ), static pressure at nozzle exit plane ( $p_e$ ), ambient (or atmospheric) pressure ( $p_{amb}$ ) [5].

### 1.3. History of Development in Rocket Engine

The preliminary discussion form where the idea of a rocket engine established in human civilization is very prominent, the discussion in the context of the historic development in gunpowder based fire crackers followed by the development of conceptual law of conservation of energy/momentum. Current propellant based rocket engines have traveled a long journey of ups and downs.

#### 1.3.1. Firecrackers, Gunpowder

Just when the first true rockets appeared is unclear. Stories of early rocket-like devices appear sporadically through the historical records of various cultures. Perhaps the first true rockets were accidents. In the first century A.D., the Chinese reportedly had a simple form of gunpowder made from saltpeter, sulfur, and charcoal dust. To create explosions during religious festivals, they filled bamboo tubes with a mixture and tossed them into fires. Perhaps some of those tubes failed to explode and instead skittered out of the fires, propelled by the gasses and sparks produced by the burning gunpowder. The Chinese began experimenting with the gunpowder-filled tubes. At some point, they attached bamboo tubes to arrows and launched them with bows. Soon they discovered that these gunpowder tubes could launch themselves just by the power produced from the escaping gas. The true rocket was born [3].



Figure 1.2. Gunpowder tubed rocket [4]

The date reporting the first use of true rockets was in 1232. At this time, the Chinese and the Mongols were at war with each other. During the battle of Kai-Keng, the Chinese repelled the Mongol invaders by a barrage of "arrows of flying fire." [4] These fire-arrows were a simple form of a solid-propellant rocket. A tube, capped at one end, contained gunpowder. The other end was left open and the tube was attached to a long stick. When the powder was ignited, the rapid burning

of the powder produced fire, smoke, and gas that escaped out the open end and produced a thrust. The stick acted as a simple guidance system that kept the rocket headed in one general direction as it flew through the air. It is not clear how effective these arrows of flying fire were as weapons of destruction, but their psychological effects on the Mongols must have been formidable.

On the day of the flight, Wan-Hu sat himself on the chair and gave the command to light the rockets. Forty-seven rocket assistants, each armed with torches, rushed forward to light the fuses. In a moment, there was a tremendous roar accompanied by billowing clouds of smoke. When the smoke cleared, Wan-Hu and his flying chair were gone. No one knows for sure what happened to Wan-Hu, but it is probable that if the event really did take place Wan-Hu and his chair were blown to pieces.

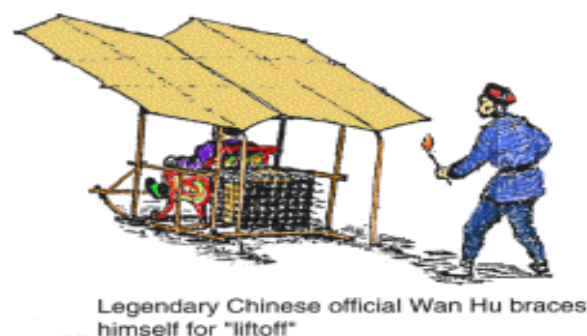


Figure 1.3. Wan-Hu flying rocket [3]

Fire-arrows were as apt to explode as to fly. During the latter part of the 17th century, the scientific foundations for modern rocketry were laid by the great English scientist Sir Isaac Newton (1642-1727). Newton organized his understanding of physical motion into three scientific laws. The laws explain how rockets work and why they are able to work in the vacuum of outer space. Newton's laws soon began to have a practical impact on the design of rockets. About 1720, a Dutch professor, Willem Gravesande, built model cars propelled by jets of steam [5]. Rocket experimenters in Germany and Russia began working with rockets with a mass of more than 45 kilograms. Some of these rockets were so powerful that their escaping exhaust flames bored deep holes in the ground even before lift-off.

During the end of the 18th century and early into the 19th, rockets experienced a brief revival as a weapon of war. The success of Indian rocket barrages against the British in 1792 and again in 1799 caught the interest of an artillery expert, Colonel William Congreve [5]. Congreve set out to design rockets for use by the British military. The Congreve rockets were highly successful in battle. Used by British ships to pound Fort McHenry in the War of 1812, they inspired Francis Scott Key to write "the rockets' red glare," words in his poem that later became The Star-Spangled Banner. An Englishman, William Hale, developed a technique called spin stabilization. In this method, the escaping exhaust gases struck small vanes at the bottom of the rocket, causing it to spin much as a bullet does in flight. Variations of the principle are still used today.[6]

In 1898, a Russian schoolteacher, Konstantin Tsiolkovsky (1857-1935), proposed the idea of space exploration by rocket. In a report he published in 1903, Tsiolkovsky suggested the use of liquid propellants for rockets in order to achieve greater range [5]. Tsiolkovsky stated that the speed and range of a rocket were limited only by the exhaust velocity of escaping gases. For his ideas, careful research, and great vision, Tsiolkovsky has been called the father of modern astronautics.

Early in the 20th century, an American, Robert H. Goddard (1882-1945), conducted practical experiments in rocketry. He had become interested in a way of achieving higher altitudes than were possible for lighter-than-air balloons [6]. He published a pamphlet in 1919 entitled *A Method of Reaching Extreme Altitudes*. It was a mathematical analysis of what is today called the meteorological sounding rocket.

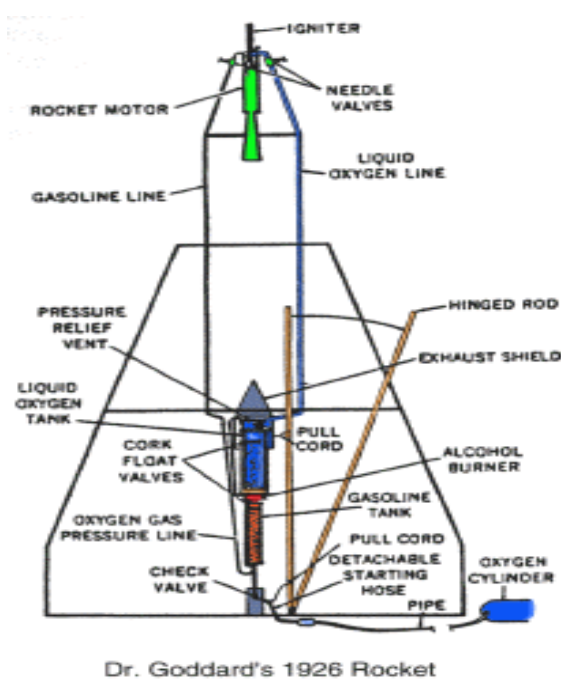


Figure 1.4. Goddard's model rocket [6]

Goddard's earliest experiments were with solid-propellant rockets. In 1915, he began to try various types of solid fuels and to measure the exhaust velocities of the burning gases. While working on solid-propellant rockets, Goddard became convinced that a rocket could be propelled better by liquid fuel. No one had ever built a successful liquid-propellant rocket before [7]. It was a much more difficult task than building solid-propellant rockets. Fuel and oxygen tanks, turbines, and combustion chambers would be needed. In spite of the difficulties, Goddard achieved the first successful flight with a liquid propellant rocket on March 16, 1926.

Fueled by liquid oxygen and gasoline, the rocket flew for only two and a half seconds, climbed 12.5 meters, and landed 56 meters away in a cabbage patch. By today's standards, the flight was unimpressive, but like the first powered airplane flight by the Wright brothers in 1903, Goddard's gasoline rocket was the forerunner of a whole new era in rocket flight. Goddard's experiments in liquid-propellant rockets continued for many years [8]. His rockets became bigger and flew higher. He developed a

gyroscope system for flight control and a payload compartment for scientific instruments. Parachute recovery systems were employed to return rockets and instruments safely. Goddard, for his achievements, has been called the father of modern rocketry.

A third great space pioneer, Hermann Oberth (1894-1989) born on June 25, 1894 in Hermannstadt (Transylvania), and died on December 28, 1989 in Nuremberg, Germany, published a book in 1923 about rocket travel into outer space. His writings were important. Because of them, many small rocket societies sprang up around the world.

In Germany, the formation of one such society, the Verein für Raumschiffahrt (Society for Space Travel), led to the development of the V-2 rocket, which was used against London during World War II [9].

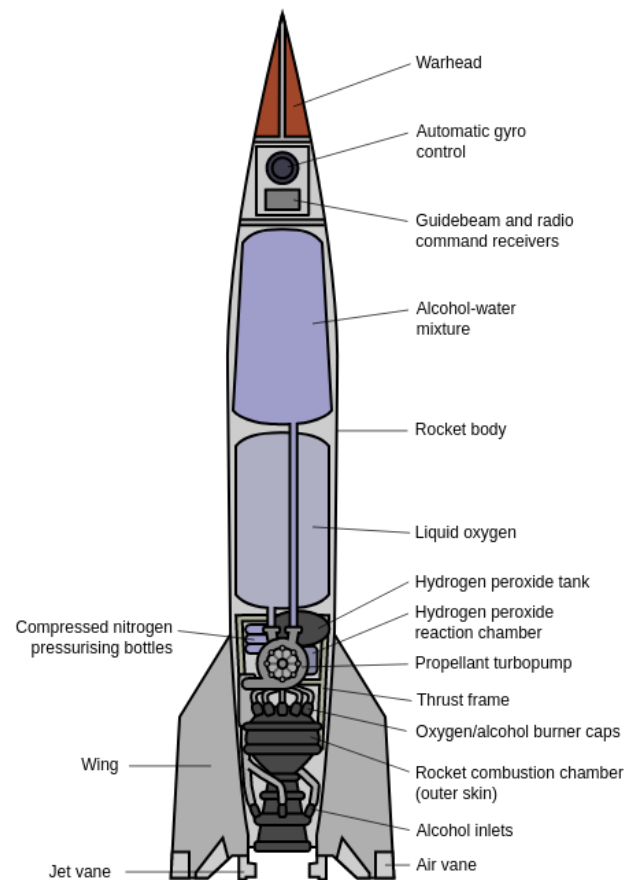


Figure 1.5. German V-2 missile model [6]

The V-2 rocket (in Germany called the A-4) was small by comparison to today's rockets. It achieved its great thrust by burning a mixture of liquid oxygen and alcohol at a rate of about one ton every seven seconds. Once launched, the V-2 was a formidable weapon that could devastate whole city blocks.

The German scientists, including Wernher Von Braun, were amazed at the progress Goddard had made. Both the United States and the Soviet Union realized the potential of rocketry as a military weapon and began a variety of experimental programs. At first, the United States began a program with high-altitude atmospheric sounding rockets, one of Goddard's early ideas. Later, a variety of medium- and long-range intercontinental ballistic missiles were developed. These became Missiles such as the Redstone,

Atlas, and Titan would eventually launch astronauts into space. On October 4, 1957, the world was stunned by the news of an Earth-orbiting artificial satellite launched by the Soviet Union [4]. Called Sputnik I, the satellite was the first successful entry in a race for space between the two superpower nations. Less than a month later, the Soviets followed with the launch of a satellite carrying a dog named Laika on board. Laika survived in space for seven days before being put to sleep before the oxygen supply ran out [5].

A few months after the first Sputnik, the United States followed the Soviet Union with a satellite of its own. Explorer I was launched by the U.S. Army on January 31, 1958 [6]. In October of that year, the United States formally organized its space program by creating the National Aeronautics and Space Administration (NASA). NASA became a civilian agency with the goal of peaceful exploration of space for the benefit of all humankind [6]. Soon, many people and machines were being launched into space. Astronauts orbited Earth and landed on the Moon. Robot spacecraft traveled to the planets. Space was suddenly opened up to exploration and commercial exploitation. Satellites enabled scientists to investigate our world, forecast the weather, and to communicate instantaneously around the globe.

As the demand for more and larger payloads increased, a wide array of powerful and versatile rockets had to be built. Since the earliest days of discovery and experimentation, rockets have evolved from simple gunpowder devices into giant vehicles capable of traveling into outer space. Rockets have opened the universe to direct exploration by humankind.

### 1.3.2. Propellant (Fuel/Oxidizer)

Firstly, in the vein of the propellant, in the context of gas propellant, chemical propellants in common use deliver specific impulse values ranging from about 175 up to about 300 seconds [10]. The most energetic chemical propellants are theoretically capable of specific impulses up to about 400 seconds [10]. High values of specific impulse are obtained from high exhaust-gas temperature, and from exhaust gas having very low (molecular) weight. To be efficient, therefore, a propellant should have a large heat of combustion to yield high temperatures, and should produce combustion products containing simple, light molecules embodying such elements as hydrogen (the lightest), carbon, oxygen, fluorine, and the lighter metals (aluminum, beryllium, lithium). Another important factor is the density of a propellant. A given weight of dense propellant can be carried in a smaller, lighter tank than the same weight of a low-density propellant. Liquid hydrogen, for example, is energetic and its combustion gasses are light. However, it is a very bulky substance, requiring large tanks. The dead weight of these tanks partly offsets the high specific impulse of the hydrogen propellant [1].

Other criteria must also be considered in choosing propellants. Some chemicals that yield excellent specific impulse create problems in engine operation. Some are not adequate as coolants for the hot thrust-chamber walls [1]. Others exhibit peculiarities in combustion that render their use difficult or impossible. Some are unstable to varying degrees, and cannot be safely stored or

handled. Such features inhibit their use for rocket propulsion.

Unfortunately, almost any propellant that gives good performance is apt to be a very active chemical; hence, most propellants are corrosive, flammable, or toxic, and are often all three. One of the most tractable liquid propellants is gasoline [2]. But while it is comparatively simple to use, gasoline is, of course, highly flammable and must be handled with care. Many propellants are highly toxic, to a greater degree even than most war gasses; some are so corrosive that only a few special substances can be used to contain them; some may burn spontaneously upon contact with air, or upon contacting any organic substance, or in certain cases upon contacting most common metals. Also essential to the choice of a rocket propellant is its availability. In some cases, in order to obtain adequate amounts of a propellant, an entire new chemical plant must be built. And because some propellants are used in very large quantities, the availability of raw materials must be considered [1].

Secondly, for the vein of solid chemical propellant, two general types of solid propellants are in use. The first, the so-called double-base propellant, consists of nitrocellulose and nitroglycerin, plus additives in small quantities. There is no separate fuel and oxidizer. The molecules are unstable, and upon ignition they break apart and rearrange themselves, liberating large quantities of heat. These propellants lend themselves well to smaller rocket motors [1]. They are often processed and formed by extrusion methods, although casting has also been employed. The other type of solid propellant is the composite. Here, separate fuel and oxidized chemicals are used, intimately mixed in the solid grain [2].

The oxidizer is usually ammonium nitrate, potassium chlorate, or ammonium chlorate, and often comprises as much as four-fifths or more of the whole propellant mix. The fuels used are hydrocarbons, such as asphalt-type compounds, or plastics. Because the oxidizer has no significant structural strength, the fuel must not only perform well but must also supply the necessary form and rigidity to the grain. Much of the research in solid propellants is devoted to improving the physical as well as the chemical properties of the fuel. Ordinarily, in processing solid propellants the fuel and oxidizer components are separately prepared for mixing, the oxidizer being a powder and the fuel a fluid of varying consistency [1]. They are then blended together under carefully controlled conditions and poured into the prepared rocket case as viscous semisolid. They are then caused to set in curing chambers under controlled temperature and pressure. Solid propellants offer the advantage of minimum maintenance and instant readiness. However, the more energetic solids may require carefully controlled storage conditions, and may offer handling problems in the very large sizes, since the rocket must always be carried about fully loaded. Protection from mechanical shocks or abrupt temperature changes that may crack the grain is essential [3].

Finally, liquid propellant is also most in common use by space centers. Most liquid chemical rockets use two separate propellants: a fuel and an oxidizer. Typical fuels include kerosene, alcohol, hydrazine and its derivatives, and liquid hydrogen [1]. Many others have been tested and

used. Oxidizers include nitric acid, nitrogen tetroxide, liquid oxygen, and liquid fluorine. Some of the best oxidizers are liquefied gasses, such as oxygen and fluorine, which exist as liquids only at very low temperatures; this adds greatly to the difficulty of their use in rockets [4]. Most fuels, with the exception of hydrogen, are liquids at ordinary temperatures. Certain propellant combinations are *hypergolic*; that is, they ignite spontaneously upon contact of the fuel and oxidizer. Others require an igniter to start them burning, although they will continue to burn when injected into the flame of the combustion chamber. In general, the liquid propellants in common use yield specific impulses superior to those of available solids [9]. On the other hand, they require more complex engine systems to transfer the liquid propellants.

### 1.3.3. Exterior Metals and Structure

The structural system, or frame, is similar to the fuselage of an airplane. The frame is made from very strong but lightweight materials, like titanium or aluminum, and usually employs long "stringers" which run from the top to the bottom which are connected to "hoops" which run around the circumference. The "skin" is then attached to the stringers and hoops to form the basic shape of the rocket. The skin may be coated with a thermal protection system to keep out the heat of air friction during flight and to keep in the cold temperatures needed for certain fuels and oxidizers.

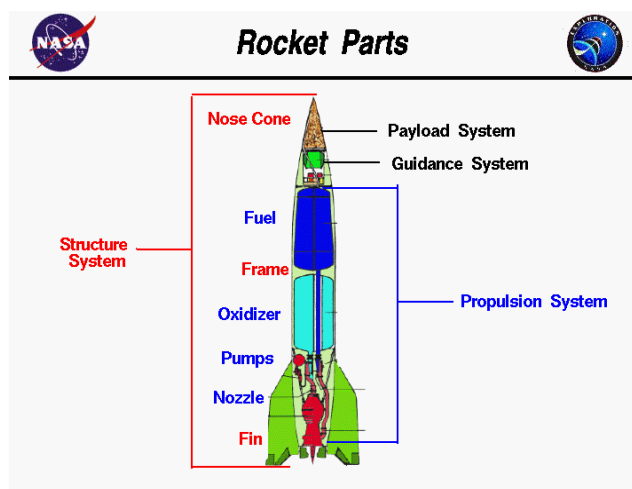


Figure 1.6. External system of rocket [6]

Fins are attached to some rockets at the bottom of the frame to provide stability during the flight. Most of the exterior parts are made with multi-layers, these layers are usually made of poly-imide or polyester films (types of plastics) coated with very thin layers of aluminum.

The payload system of a rocket depends on the rocket's mission. The earliest payloads on rockets were fireworks for celebrating holidays. The payload of the German V2, shown in the figure, was several thousand pounds of explosives [17]. Following World War II, many countries developed guided ballistic missiles armed with nuclear warheads for payloads. The same rockets were modified to launch satellites with a wide range of missions; communications, weather monitoring, spying, planetary exploration, and observatories, like the Hubble Space

Telescope. Special rockets were developed to launch people into earth orbit and onto the surface of the Moon.

The guidance system of a rocket may include very sophisticated sensors, on-board computers, radars, and communication equipment to maneuver the rocket in flight. Many different methods have been developed to control rockets in flight. The V2 guidance system included small vanes in the exhaust of the nozzle to deflect the thrust from the engine. Modern rockets typically rotate the nozzle to maneuver the rocket. The guidance system must also provide some level of stability so that the rocket does not tumble in flight [11].

As you can see on the figure, most full scale rockets are propulsion systems. There are two main classes of propulsion systems, liquid rocket engines and solid rocket engines. The V2 used a liquid rocket engine consisting of fuel and oxidizer (propellant) tanks, pumps, a combustion chamber with nozzle, and the associated plumbing. The Space Shuttle, Delta II, and Titan III all use solid rocket strap-ons [12]. The various rocket parts described above have been grouped by function into structure, payload, guidance, and propulsion systems. There are other possible groupings. For the purpose of weight determination and flight performance, engineers often group the payload, structure, propulsion structure (nozzle, pumps, tanks, etc.), and guidance into a single empty weight parameter. The remaining propellant weight then becomes the only factor that changes with time when determining rocket performance [7].

### 1.3.4. Interior Metals and Structure

Rockets that use the common construction materials such as aluminum, steel, nickel or copper alloys must employ cooling systems to limit the temperatures that engine structures experience. In the context of various rocket engine parts, propellant tank, oxidizer tank, individual two technically sensitive pumps, combustion chamber and exhaust are the most important parts which plays a vital role for good efficiency as well as safety of the rocket [5].

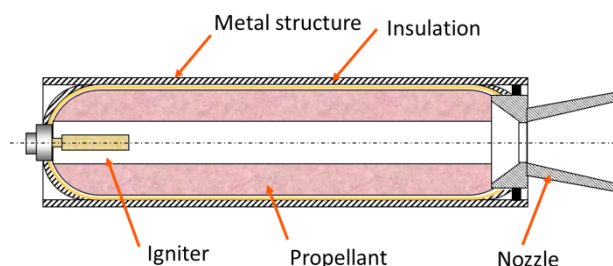


Figure 1.7. Internal structure of combustion chamber [5]

Exploring the internal structure of the combustion chamber which is most important of all, it is made of five layers in total. Outermost layer is the metal structure, the second layer is the insulator which controls the heat produced by burning of propellant in the inner igniter chamber. Outer metal is basically made with the aluminum, stainless steels, titanium alloys, aluminum alloys, niobium alloys, alloy steels, cobalt-base alloys, and copper alloys also are employed, according to performance demands [20]. The performance of a rocket

engine is a function of the pressure which can be obtained in its combustion chamber.

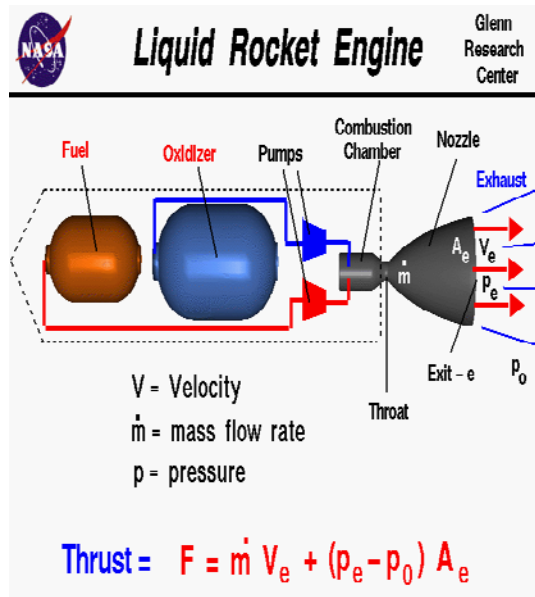


Figure 1.8. The fuel and oxidizer tank [6]

Fuel tank is small in volume as compared to the oxidizer tank but very important in rocket engine. It made of beryllium-copper, stainless steel, Duralumin, and dow- metal, with the same strength and capacity would be about equal in weight, provided they were used to operate at ordinary temperatures. However, the steel used to create storage tanks for oxidizer into two main categories: carbon steel and stainless steel [13].

Table 1.1. The brief history of the evolution of rocket engine [24]

| Rocket engine type     | Date    | Propellant used              | Oxidizer used           |
|------------------------|---------|------------------------------|-------------------------|
| Wan-Hu flying rocket   | 1000 BC | gunpowder                    | Atmospheric oxygen      |
| Gunpowder tubed rocket | 1232 AD | gunpowder                    | Atmospheric oxygen      |
| Iron cased rocket      | 1792 AD | gunpowder                    | Atmospheric oxygen      |
| Congreve Rocket        | 1802 AD | Propellant mixture           | Atmospheric oxygen      |
| Goddard's model rocket | 1912 AD | gasoline                     | liquid oxygen           |
| V-2 rocket             | 1942AD  | water-alcohol                | liquid oxygen           |
| Sputnik I              | 1957AD  | Kerosene                     | Liquid oxygen           |
| Apollo 11              | 1969AD  | Liquid hydrogen              | Liquid oxygen           |
| Falcon 9               | 2018 AD | rocket-grade kerosene (RP-1) | cryogenic liquid oxygen |
| Long March-5B rocket   | 2020AD  | Liquid hydrogen and Kerosene | Liquid oxygen           |

## 1.4. Statement of Problem

Specific impulse produced by a propellant used in a rocket engine plays a prominent role for gaining good efficiency of a rocket engine. Hence, the calculation of specific impulse ( $I_{sp}$ ) of all above-mentioned propellant used by various rockets is mandatory. The most important metric for the efficiency of a rocket engine is impulse per unit of propellant, this is called specific impulse. This is either measured as a speed (the effective exhaust velocity in m/s or ft/s) or as a time (seconds) [3]. For example, if an engine producing 100 pounds of thrust runs for 320

seconds and burns 100 pounds of propellant, then the specific impulse is 320 seconds. The higher the specific impulse, the less propellant is required to provide the desired impulse [5].

Throughout the history of the rocket engine, various types of propellant have been used to gain the enough exhaust velocity required for the propulsion [7]. Here, we calculate the net thrust produced by all important propellant used by historic rocket engines which play proportional role to generate specific impulse which ultimately helps to establish the efficiency of a rocket engine [2].

To recapitulate, we analyze the reason for changes or improvements brought in propellants of rocket engines on the basis of their energy efficiency which is maintained by the particular propellant's specific impulse.

## 1.5. Objectives

### 1.5.1. General Objectives

- To calculate specific impulse of various rocket engine propellants used in various rockets.

### 1.5.2. Specific Objectives

- To calculate the specific impulse ( $I_{sp}$ ) produced by various rocket propellants.
- To Compare the important parameters (specific impulse, net thrust-mass ratio and energy efficiency) of the selected historic rocket engines evolved by human effort.

## 2. Literature Review

### 2.1. Literature Review

This section presents an overview of propellant efficiency and how they are tested and controlled. It is the belief of the author that all the referenced literature used in this review can be considered credible. The calculation and comparison of specific impulse, net thrust – mass ratio and energy efficiency of rocket propellant is a genuine method to analyze the improvements brought in fuel and oxidizer space launch engines throughout history. Some research related to this study are reviewed here.

Erik Andersson, (2019) did the research on the topic, "Preliminary design of a small-scale liquid-propellant rocket engine testing platform" and concluded on his basis of the literature review and using other test platform designs as reference, a design of a complete propellant feed assembly with all required components as part of the propulsion system and the specific impulse of a propellant plays a important role in the engine efficiency of the rocket engine.

Anselm Ho Yen Phing, (2008) conducted a research paper on the topic, "Simulating Combustion Flowing a Rocket Chamber" where he cited that, considering the time taken for acquiring a reasonable result, the propellant volume source would also make a better choice for future simulations. The only solution to determine if the volume source is correct is to have a simulation with the chemistry reaction of propellants. Both results did give a boundary layer efficiency of 98% approximately. This could then be used with other efficiency values to obtain the rocket

engine's effective performance. Results should also be obtained using the correct temperature distributions to see if there is a marginal difference in boundary layer efficiency.

Michal Málek Prague (2019) elaborated a study on the topic, "Design and characterization of small solid-propellant rocket engine" During his experimental research on the solid propellant, he found that both thrust and total impulse were slightly worse than their calculated expectations, but that is understandable as those were theoretically perfect results supported with several simplifying assumptions. The burn time was significantly longer than expected, mainly due to slower burn rate of the propellant.

Ideal rocket equation, named after Russian scientist Konstantin Tsiolkovsky who independently derived it and published "Ideal rocket equation" in his 1903 work. Here, in his equation relates the  $\Delta v$  (the maximum change of velocity of the rocket if no other external forces act) to the effective exhaust velocity and the initial and final mass of a rocket, or other reaction engine. Identically, he was able to relate velocity change or acceleration, initial mass of rocket including propellant, final total mass of the rocket after combustion of propellant, effective exhaust velocity, specific impulse in dimension of time, standard gravity and natural logarithm.

Robert H. Goddard (1919), who is also known as the pioneer of modern rocketry published an article entitled, "Method of reaching extreme altitudes" where he mentioned the important role of the propellant used in a rocket engine which determines the efficient performance. In conclusion, he cited that, "A theoretical treatment of the rocket principle shows that if the velocity of expulsion of the gas were considerably increased and the ratio of propellant material to the entire rocket were also increased, a tremendous increase in range would result, from the fact that there two quantities enter exponentially in the expression for the initial mass of the rocket is necessary to rise a given mass to the given height."

Various books, for instance, perhaps the most referenced source material for this chapter is the 9th edition of Rocket Propulsion Elements, written by George P. Sutton and Oscar Biblarz. The book has been used for a long time, especially within academia, and "has been regarded as the single most authoritative source book on rocket propulsion technology". As the authors of the book state: Since its first edition in 1949 this book has been a most popular and authoritative work in rocket propulsion and has been acquired by at least 77,000 students and professionals in more than 35 countries. It has been used as a text in graduate and undergraduate courses at about 55 universities. It is the longest living aerospace book ever, having been in print continuously for 67 years.

It is cited in two prestigious professional awards of the American Institute of Aeronautics and Astronautics. Earlier editions have been translated into Russian, Chinese, and Japanese. The authors have given lectures and three-day courses using this book as a text in colleges, companies and Government establishments. In one company all new engineers are given a copy of this book and asked to study it [8] Another document referenced greatly not only in this chapter but throughout the report as an integral part in the design development, is the manual entitled HOW to DESIGN, BUILD and TEST SMALL LIQUID-FUEL ROCKET ENGINES by Leroy

Krzycki - described as a "classic text for experimental and "amateur" rocket scientists, engineers, and technicians" [9] Since its first printing in 1967 it has been, and still is, a popular source of information for designing simple and safe rocket engines for anyone with limited experience in the field. It describes the complete process, from design concept to the manufacturing and safe testing of the finished product, in a very comprehensible manner making it an ideal source material for this application [10].

Essentially, this feat is achieved by applying Newton's third law: For every action there's an equal and opposite reaction. By accelerating and expelling mass, or particles - also called the Working Fluid (WF)- out of the aft end of the rocket, a force is generated towards the ground which, in turn, produces reaction force applied to the rocket in the opposite direction. This reaction force is what is called thrust and it is directed along the length of the rocket, towards the front end and going through its center of gravity. WF is, as such, the name for the collection of particles being accelerated and driven out of the rocket to create thrust. In its initial state, while stored in the system and at rest before launch, this particle collection is called propellant.

Depending on the method being used for acceleration, the propellant either changes physical states or does not. In the latter case, the terms WF and propellant can be used interchangeably. The supply of propellant in a rocket is critical - From [11], p. 31: "The engine's ability to produce thrust will endure only so long as the supply of particles, or working fluid, holds out". The amount of propellant to be loaded in a propulsion system is therefore something that must be carefully calculated, to make sure the rocket can perform nominally until mission completion. The efficiency of a propulsion system is partly dependent on the efficiency of the propellant used. This efficiency is measured by a parameter called specific impulse, or  $I_{sp}$ , and it can be described as "the ratio of the amount of thrust produced to the weight flow of the propellants".

## 3. Methodology

### 3.1. Study Area

This research is based on the secondary data which is extracted from the research articles of various thesis documents, internet sources like Wikipedia, Journals and various books associated with rocket propellant science. Hence, collecting and studying the data of various engine's propellants and structures made till date to overcome various efficiency challenges, analyzing the current potential and challenges; and future visions with possible challenges is important, conducted as an spontaneous effort by NASA, ISRO, CNSA, Space-X and other space agencies. This theoretical research will help us to find scope, challenge and method to solve those chaos related to space engine's efficiency in multiple time frames. Historic data will give us a mind set about our past experience of solving restrictions giving us general ideas to solve future probable problems in propellant or fuel and design of rocket engine. The historic data of the various propellants is obtained from the various major websites of the following institutions.

Table 3.1. The list of data sources [24]

|            |                                                                                                       |
|------------|-------------------------------------------------------------------------------------------------------|
| Weikipedia | <a href="https://en.wikipedia.org/wiki/Rocket_engine">https://en.wikipedia.org/wiki/Rocket_engine</a> |
| NASA       | <a href="https://www.nasa.gov/">https://www.nasa.gov/</a>                                             |
| CNSA       | <a href="http://www.cnsa.gov.cn/english/">http://www.cnsa.gov.cn/english/</a>                         |
| Space X    | <a href="https://www.spacex.com/">https://www.spacex.com/</a>                                         |
| ISRO       | <a href="http://www.isro.gov.in">www.isro.gov.in</a>                                                  |

### 3.2. Determining Specific Impulse of Various Propellants

Specific impulse (usually abbreviated  $I_{sp}$ ) is a measure of how effectively a rocket uses propellant or a jet engine uses fuel. Specific impulse can be calculated in a variety of ways with different units [17]. By definition, it is the total impulse (or change in momentum) delivered per unit of propellant consumed and is dimensionally equivalent to the generated thrust divided by the propellant mass or weight flow rate. If mass (kilogram, pound-mass, or slug) is used as the unit of propellant, then specific impulse has units of velocity. If weight (newton or pound-force) is used instead, then specific impulse has units of time (seconds). Multiplying flow rate by the standard gravity ( $g_0$ ) converts specific impulse from the weight basis to the mass basis.

A propulsion system with a higher specific impulse uses the mass of the propellant more efficiently. In the case of a rocket or other vehicle governed by the Tsiolkovsky rocket equation, this means less propellant needed for a given delta-V. In rockets, this means that the vehicle the engine is attached to can more efficiently gain altitude and velocity [14]. This effectiveness is less important in jet aircraft that use ambient air for combustion, and carry payloads that are much heavier than the propellant. Specific impulse can include the contribution to impulse provided by external air that has been used for combustion and is exhausted with the spent propellant. Jet engines use outside air, and therefore have a much higher specific impulse than rocket engines [7]. The specific impulse in terms of propellant mass spent has units of distance per time, which is a notional velocity called the effective exhaust velocity. This is higher than the actual exhaust velocity because the mass of the combustion air is not being accounted for. Actual and effective exhaust velocity are the same in rocket engines operating in a vacuum.

The amount of propellant can be measured either in units of mass or weight. If mass is used, specific impulse is an impulse per unit mass, which dimensional analysis shows to have units of speed, specifically the effective exhaust velocity. As the SI system is mass-based, this type of analysis is usually done in meters per second [6]. If a force-based unit system is used, impulse is divided by propellant weight (weight is a measure of force), resulting in units of time (seconds). These two formulations differ from each other by the standard gravitational acceleration ( $g_0$ ) at the surface of the earth [20].

The rate of change of momentum of a rocket (including its propellant) per unit time is equal to the thrust. The higher the specific impulse, the less propellant is needed to produce a given thrust for a given time and the more efficient the propellant is [15]. This should not be confused with the physics concept of energy efficiency,

which can decrease as specific impulse increases, since propulsion systems that give high specific impulse require high energy to do so.

When calculating specific impulse, only propellant carried with the vehicle before use is counted. For a chemical rocket, the propellant mass therefore would include both fuel and oxidizer. In rocketry, a heavier engine with a higher specific impulse may not be as effective in gaining altitude, distance, or velocity as a lighter engine with a lower specific impulse, especially if the latter engine possesses a higher thrust-to-weight ratio [4]. This is a significant reason for most rocket designs having multiple stages. The first stage is optimized for high thrust to boost the later stages with higher specific impulse into higher altitudes where they can perform more efficiently.

The time unit of seconds to measure the performance of a propellant/engine combination can be thought of as "How many seconds this propellant can accelerate its own initial mass at 1 g". The more seconds it can accelerate its own mass, the more delta-V it delivers to the whole system. For all vehicles, specific impulse (impulse per unit weight-on-Earth of propellant) in seconds can be defined by the following equation [17]:

$$F_{thrust} = \bar{g}_0 \cdot I_{sp} \cdot \dot{m} \quad (3.1)$$

where:

$F_{thrust}$  is the thrust obtained from the engine (newtons or pound force),

$\bar{g}_0$  is the standard gravity, which is nominally the gravity at Earth's surface ( $m/s^2$  or  $ft/s^2$ ),

$I_{sp}$  is the specific impulse measured (seconds),

$\dot{m}$  is the mass flow rate of the expended propellant (kg/s or slugs/s)

[6] The English unit pound mass is more commonly used than the slug, and when using pounds per second for mass flow rate, the conversion constant  $g_0$  becomes unnecessary, because the slug is dimensionally equivalent to pounds divided by  $g_0$ :

$$F_{thrust} = I_{sp} \cdot \dot{m} \quad (3.2)$$

$I_{sp}$  in seconds is the amount of time a rocket engine can generate thrust, given a quantity of propellant whose weight is equal to the engine's thrust [20]. The advantage of this formulation is that it may be used for rockets, where all the reaction mass is carried on board, as well as airplanes, where most of the reaction mass is taken from the atmosphere. In addition, it gives a result that is independent of units used (provided the unit of time used is the second). In rocketry, the only reaction mass is the propellant, so an equivalent way of calculating the specific impulse in seconds is used. Specific impulse is defined as the thrust integrated over time per unit weight on Earth of the propellant [6].

$$I_{sp} = \frac{v_e}{g_0} \quad (3.3)$$

where,

$I_{sp}$  is the specific impulse measured in seconds,

$v_e$  is the average exhaust speed along the axis of the engine (in  $ft/s$  or  $m/s$ ),

$g_0$  is the standard gravity (in  $ft/s^2$  or  $m/s^2$ ).

Table 3.2. Various units of specific impulse [9]

| Units                    | Specific Impulse(I <sub>sp</sub> ) |                  | Effective exhaust velocity | Specific fuel consumption |
|--------------------------|------------------------------------|------------------|----------------------------|---------------------------|
|                          | By weight                          | By Mass          |                            |                           |
| SI units                 | x s                                | 9.80665·x N·s/kg | 9.80665·x m/s              | 101,972/x g/(kN·s)        |
| English engineering unit | x s                                | x lbf·s/lb       | 32.17405·x ft/s            | 3,600/x lb/(lbf·hr)       |

The most common unit for specific impulse is the second, as values are identical regardless of whether the calculations are done in SI, imperial, or customary units. Nearly all manufacturers quote their engine performance in seconds, and the unit is also useful for specifying aircraft engine performance. Meters per second are numerically equivalent to Newton-seconds per kg (N·s/kg), and SI measurements of specific impulse can be written in terms of either units interchangeably [6].

For rockets and rocket-like engines such as ion thrusters a higher I<sub>sp</sub>, implies lower energy efficiency, as the power needed to run the engine is as follows [17]:

$$\frac{dm}{dt} \frac{v_e^2}{2} \quad (3.4)$$

where,  $v_e$  is the actual exhaust jet velocity and from momentum considerations the thrust generated is [17]:

$$\frac{dm}{dt} v_e \quad (3.5)$$

Dividing the power by the thrust to obtain the specific power requirements we get [17]:

$$\frac{v_e}{2} \quad (3.6)$$

With constant thrust, the power needed increases as the exhaust velocity, leading to a lower energy efficiency per unit thrust. However, real-world vehicles are also limited in the mass amount of propellant they can carry [17]. At low exhaust velocity the amount of reaction mass increases, at very high exhaust velocity the energy required becomes prohibitive.

Theoretically, for a given delta-v, in space, among all fixed values for the exhaust speed the value [17],

$$v_e = 0.6275\Delta v \quad (3.7)$$

### 3.3. Method of Data Collection

Hence, collecting and studying the data of various engine's propellants and structures made till date to overcome various efficiency challenges, analyzing the current potential and challenges; and future visions with possible challenges is important, conducted as an spontaneous effort by NASA, ISRO, CNSA, Space-X and other space agencies.

This theoretical research will help us to find scope, challenge and method to solve those chaos related to space engine's efficiency in multiple time frames. Historic data will give us a mind set about our past experience of solving restrictions giving us general ideas to solve future probable problems in propellant or fuel and design of rocket engine [16].

History of primitive engines initiated since 1794 in Thomas Mead's gas engine, Robert Street's combustion engine in 1794, Francois Isaac de Rivaz's electric spark followed by industrial utilization of Samuel Brown's engine in 1823 [17]. Subsequently, all had set a base for the first liquid propellant rocket engine of Robert Goddard's facilitated by Felix Wankel's piston-less eccentric rotary engine design triggering today's biggest space travel vision ultimately necessary for modern world in order to understand universe, and space exploration coupled with mass interstellar emigration [17]. Hence, we shall discuss the historical problems of space engines with their solution made till date, instantaneous situation and complication in space engine coupled with future vision and obstacles with their suitable solutions [17].

### 3.4. NASA, ISRO, CNSA, Space-X Historic Official Data Analysis of Specific Impulse of Propellants

Firstly, NASA is one the main international institutions for rocket science, which is publishing various papers related to space exploration followed by various facts about the specific impulse associated with rocket propellant. Which data is collected and analyzed in this paper for the detailed study of specific impulse.

In the same vein, the contribution of ISRO and CNSA in the south Asian region is really inspirational, which is also regularly publishing their articles, papers and research in their official websites.

These data are also associated with the reason for choosing the propellants which is mainly based on the specific impulse provided by the particular compound used in the combustion chamber. Followed by the Space-X agency, the data opened by them are really helpful to calculate the Specific impulses of the various propellant used in their rockets.

Finally, we plot the data obtained from the above expression by the help of gnu-plot. Where, exhaust velocity of various rocket's engine propellant variation roles in the energy efficiency is obtained. In addition to that, the relation of the energy efficiency is also linked with the specific impulse of the various propellant by the help of gnu-plot coding.

## 4. Results and Discussion

### 4.1. Calculation of Specific Impulse

Calculation of the specific impulse is done by the help of the equation (3.3) discussed in the methodology as represented in the following table.

Table 4.1. Specific impulse of various propellants [17]

| Rockets                      | Propellants                                              | $I_{sp}$ , Vacuum (s) |
|------------------------------|----------------------------------------------------------|-----------------------|
| Space shuttle liquid engines | Liquid Oxygen and liquid hydrogen (LOX/LH <sub>2</sub> ) | 453                   |
| Space shuttle solid motors   | Ammonium perchlorate composite propellant (APCP)         | 268                   |
| Space Shuttle OMS            | Monomethylhydrazine and nitrogen tetroxide (NTO/MMH)     | 313                   |
| Saturn V Stage 1             | Liquid oxygen and highly refined kerosene (LOX/RP-1)     | 304                   |

However, a variable exhaust speed can be more energy efficient still. For example, if a rocket is accelerated from some positive initial speed using an exhaust speed equal to the speed of the rocket no energy is lost as kinetic energy of reaction mass, since it becomes stationary. (Theoretically, by making this initial speed low and using another method of obtaining this small speed, the energy efficiency approaches 100%, but requires a large initial mass.) [4]. In this case the rocket keeps the same momentum, so its speed is inversely proportional to its remaining mass.

During such a flight the kinetic energy of the rocket is proportional to its speed and, correspondingly, inversely proportional to its remaining mass [9]. The power needed

per unit acceleration is constant throughout the flight; the reaction mass to be expelled per unit time to produce a given acceleration is proportional to the square of the rocket's remaining mass.

The best way to deal with the specific impulse is to analyze the exhaust specific energy and relate it with the effective exhaust velocity of a rocket engine based on the various engine systems. Various engine systems have a variety of selected propellant based on the required specific impulse in order to increase the efficiency of the engine. Here on the following table, there is the comparison of different types of engine used in the jet engine on the basis of effective exhaust velocity, specific impulse and exhaust specific energy.

Table 4.2. Specific impulse of various propulsion technology [17]

| Engine                                    | Effective Exhaust velocity (m/s) | Specific impulse (s) | Exhaust specific energy (MJ/kg) |
|-------------------------------------------|----------------------------------|----------------------|---------------------------------|
| Turbofan jet engine                       | 29,000                           | 3,000                | 0.05                            |
| The Solid rocket booster                  | 2,500                            | 250                  | 3                               |
| Liquid oxygen and hydrogen                | 4,400                            | 450                  | 9.7                             |
| Iron thruster                             | 29,000                           | 3,000                | 430                             |
| VASMIR                                    | 30,000 to 1,20,000               | 3,000 to 12,000      | 1,400                           |
| Dual stage 4 Grid electronic ion thruster | 2,10,000                         | 21,400               | 22,500                          |
| Ideal photonic rocket                     | 29,97,92,458                     | 30,570,000           | 89,87,55,17,847                 |

## 4.2. Relation of Specific Impulse and Engine Efficiency

Specific impulse generated by the particular propellant in given engine type plays a prominent role in the overall efficiency of the rocket. Theoretically, by making this initial speed low and using another method of obtaining this small speed, the energy efficiency approaches 100%, but requires a large initial mass which is determined by the effective exhaust velocity [12]. Rocket engine nozzles are surprisingly efficient heat engines for generating a high speed jet, as a consequence of the high combustion temperature and high compression ratio. Rocket nozzles give an excellent approximation to adiabatic expansion which is a reversible process, and hence they give efficiencies which are very close to that of the carnot cycle [5]. Given the temperatures reached, over 60% efficiency can be achieved with chemical rockets. Therefore, comparison of such quantities are given below.

Table 4.3. Specific fuel consumption (SFC), specific impulse, and effective exhaust velocity numbers for various rocket and jet engines. [6]

| Engine Type                   | Specific fuel consumption |          | Specific impulse (s) | Effective exhaust velocity (m/s) |
|-------------------------------|---------------------------|----------|----------------------|----------------------------------|
|                               | (lb/lbf-h)                | (g/kN.s) |                      |                                  |
| NK-33 Rocket engine           | 10.9                      | 308      | 331                  | 3250                             |
| SSME rocket engine            | 7.95                      | 225      | 453                  | 4440                             |
| Ramjet                        | 4.5                       | 130      | 800                  | 7800                             |
| J-58 turbojet                 | 1.9                       | 54       | 1900                 | 19000                            |
| Eurojet Ej200                 | 1.66-1.73                 | 47-49    | 2080-2170            | 20400-21300                      |
| Rolls-Royce                   | 1.195                     | 33.8     | 3010                 | 29500                            |
| CF6-80C2B1F Turbofan          | 0.605                     | 17.1     | 5950                 | 58400                            |
| General Electric CF6 turbofan | 0.307                     | 8.7      | 11700                | 115000                           |

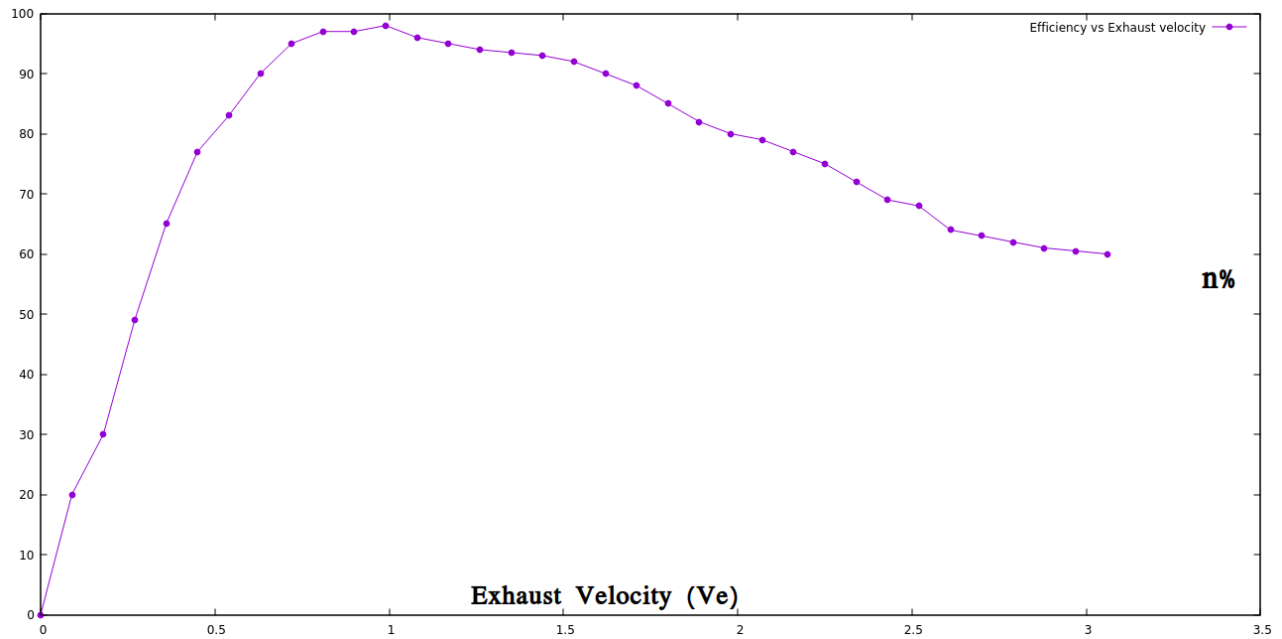


Figure 4.1. Relation of the efficiency with exhaust velocity

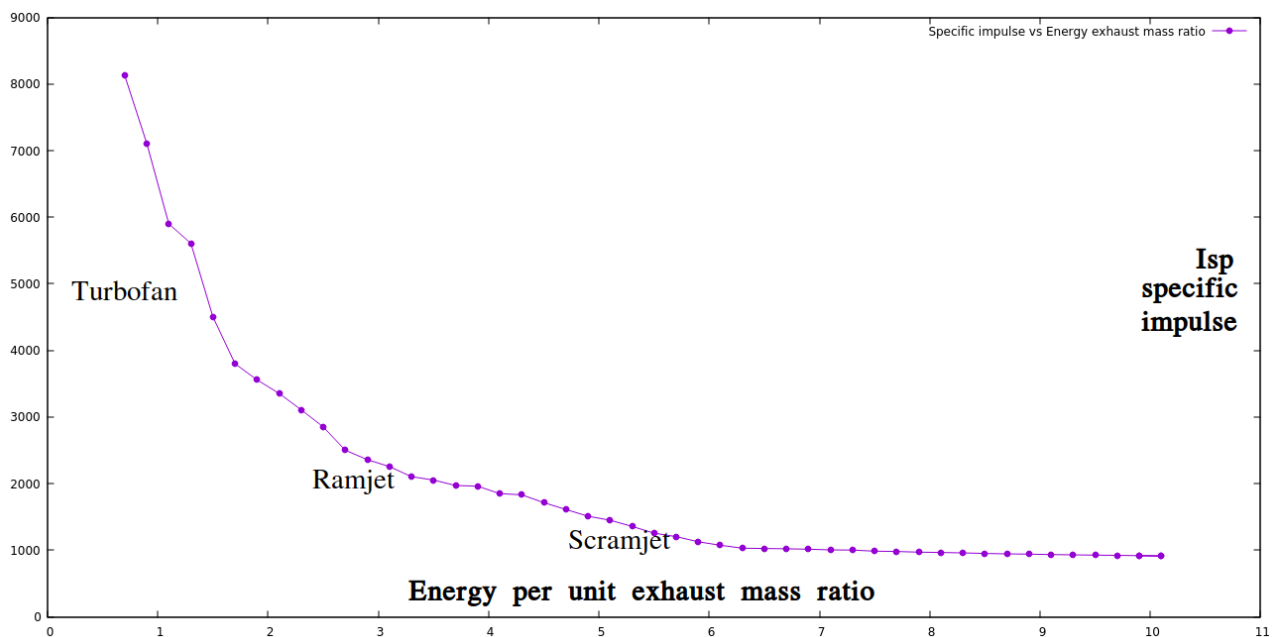


Figure 4.2. The specific impulse of various jet engines

#### 4.3. Problems Associated with Modern Rocket Engine

Rocket vehicle mechanical efficiency as a function of vehicle instantaneous speed divided by effective exhaust speed [23]. These percentages need to be multiplied by internal engine efficiency to get overall efficiency.

For a rocket employing a rocket engine the energetic efficiency is very good if the vehicle speed approaches or somewhat exceeds the exhaust velocity (relative to launch); but at low speeds the energy efficiency goes to 0% at zero speed (as with all jet propulsion) [22].

Of the liquid propellants used, density is lowest for liquid hydrogen. Although this propellant has the highest specific, its very low density (about one fourteenth that of water) requires larger and heavier turbo-pumps and

pipework, which decreases the engine's thrust-to-weight ratio (for example the RS-25) compared to those that do not (NK-33) [2].

Buzzing can be caused due to insufficient pressure drop across the injectors. It generally is mostly annoying, rather than being damaging [4]. However, in extreme cases combustion can end up being forced backwards through the injectors that can cause explosions with mono-propellants.

It is crystal clear that specific impulse generated by the particular propellant in the rocket engine plays an important role in the efficiency of the rocket engine [18]. Low specific impulse hindering the energy efficiency of the rocket is a critical problem of modern rocketry. The various propellants of turbofan jet engines, the various solid propellant, liquid oxygen and hydrogen have

comparatively low specific impulse which decrease the exhaust velocity of the aircraft. Since, energy efficiency of the aircraft is directly proportional to the exhaust velocity, the various propellant used by the current engine has serious issues in good energy efficiency [19].

#### 4.4. Solutions of the Modern Problems of Rocket Engine

In order to solve the above mentioned problems, we need to select the propellant very carefully which have very high specific impulse like fuel used in J-58 turbojet, Euro-jet EJ200, Rolls-Royce, CF6-80C2B1F Turbofan and General Electric CF6 turbofan. This high performance is due to the small volume of pressure vessels that make up the engine the pumps, pipes and combustion chambers involved [20]. The lack of inlet duct and the use of dense liquid propellant allows the pressurization system to be small and lightweight, whereas duct engines have to deal with air which has around three orders of magnitude lower density.

Liquid oxygen and highly refined kerosene (LOX/RP-1) as a propellant is best for the rocket engine as compared to Liquid Oxygen and liquid hydrogen (LOX/LH<sub>2</sub>) because (LOX/RP-1) has high specific impulse generated by the rocket engine [18]. Due to this high specific impulse generated by this propellant, the best propellant used in the rocket engine is liquid oxygen and highly refined kerosene which have maximum energy efficiency.

#### 4.5. Future of Rocket Engines

Ideal photonic rocket, the future of the rocket engine possesses the maximum specific impulse as the propellant in the rocket energy source. Hence, Solar electric propulsion could be used to send cargo to Mars ahead of a human mission. That would ensure equipment and supplies were ready and waiting for astronauts when they arrived using chemical rockets, according to Dr Jeff Sheehy, chief engineer in Nasa's Space Technology Mission Directorate [20]. With solar electric propulsion, large solar arrays unfurl to capture solar energy, which is then converted to electricity [8]. This powers something called a Hall thruster. There are pros and cons. On the upside, we need far less fuel, so the spacecraft becomes lighter. But it also takes your vehicle longer to explore our universe.

Another idea is to use chemical rockets to lift off from Earth and to land on Mars. But for the middle part of the journey, some engineers propose using something called nuclear thermal electric propulsion. Once Orion has been connected to the transfer vehicle, a nuclear electric rocket would be used to get the crew capsule and the transport module to Mars, where they link up with a Mars orbiter and lander, which are waiting in Mars' orbit [7].

In a nuclear thermal electric rocket, a small nuclear reactor heats up liquid hydrogen [11]. The gaseous form of the element expands and shoots out of the thruster. Nuclear thermoelectric is the closest new engine technology to being ready for use which has maximum specific impulse with highest exhaust velocity with required energy deficiency.

## 5. Conclusions

### 5.1. Conclusion

To recapitulate, energy efficiency of a rocket engine is directly proportional to the specific impulse of a propellant used inside a rocket engine which plays a prominent role to maintain exhaust velocity. Therefore, we shall focus further in the use of ionic repulsive propellant and nuclear thermal propellant which have maximum specific impulse with maximum exhaust velocity.

The main base for the selection of rocket's engine propellant is specific impulse ( $I_{sp}$ ) which is directly proportional to the efficiency of the rocket engine.

### List of Abbreviations

CNSA = China National Space Administration

NASA = National Aeronautics and Space Administration

ISRO = Indian Space Research Organization

LACE = Liquid Air Cycle Engine

$I_{sp}$  = specific impulse/atmospheric specific impulse

$F_n$  = total thrust of the rocket engine on the performance

$\dot{m}$  = exhaust gas mass flow

$v_e$  = effective exhaust velocity

$v_{e-opt}$  = effective jet velocity when  $P_{amb} = P_e$

$A_e$  = flow area at nozzle exit plane (or the plane where the jet leaves the nozzle if separated flow)

$p_e$  = static pressure at nozzle exit plane

$p_{amb}$  = ambient (or atmospheric) pressure

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