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Efficient Hybrid Rocket Motor Development

Rushikesh Ghodke [1], Sanjeet Jagdale[2], Aditya Kekare[3], Vishal Chougule[4], Prasad Jagdhane[5] Sairaj Patil[6],
3rd Year, B.Tech Instrumentation and Control, D.Y.Patil college of Engg., Akurdi, Pune[1,2],
3rd Year, B.Tech Electronics, DKTE's Textile and Engg. Institute, Ichalkaranji[3,4,5] ,
3rd Year, B.Tech Mechanical, D.Y.Patil College of Engg. and Technology, Kolhapur[6],
Corresponding author: Rushikesh Ghodke

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ABSTRACT: Rocket engines are used in lot of application nowadays which includes low orbit launch, satellite maneuvering, but most importantly in Space tourism which is gaining lot of traction these days but will be important aspect of space industry in near future. On of these companies Virgin Galactic is making progress in hybrid rocket engine. Hybrid propulsion is considered to be in middle of liquid and solid propulsion in verious terms. Also the space organization around the world government as well as private has agreed that future of space industry changing rapidly and new technologies and new ways to build more efficient rockets engines. Today we use Rocket technology that is old as it gets mainly we use two different types of rocket engines that are solid Rocket engines, liquid rocket engines. Although these are reliable and we are more familiar with their working but there is new type of Rocket engine that combines reusability of liquid Rocket engines and powerful thrust of solid rocket motor. With the new research we can implement these hybrid rockets in new launch vehicles for improved performance and efficiency. These engines considered simple, safe, low cost, and can throttle thrust of solid rocket. This makes these engines suitable for broad range of application**.**

I. INTRODUCTION

Rocket engines are the most sophisticated in design and construction. We as a human being are always curious about space and interstellar space. To fuel our hunger for curiosity in this subject rocket engines play the most vital part. With the improvement and innovation in this space industry we were able to land a human being on the moon through Apollo 11 mission on July 20th 1969, Landed autonomous rovers on planet like mars, and sent numerous satellites in the space and to the other planets. The most famous would be voyager mission that are still active and traveling in the darkness of interstellar space. When we look at the space industry from the beginning to till this day it's clear that we are using the same technology that helped us to get to the moon. With the changing times and rapid development of these hybrid rocket and reusable launch vehicle is necessary.

Engines like F1 that was used in the saturn 5 and space shuttles two solid rocket booster are two excellent examples of past Pinnacle rocket technology. And most of the new rockets are some what based on this technology.
Understanding of these types of engines will be very useful in creating a hybrid rocket engines as we move forwardWe are making surprising amount of progress in hybrid rocket engines. These engines can be efficient in certain applications. Although they are not used in any launch vehicle the results are promising. To Thoroughly understand this topic we need to look at both engines first in detail.

II. LIQUID ROCKET MOTOR .A1.

As name suggests it uses liquid fuel. Liquid rocket motor uses liquid fuel and liquid oxidizer and in some cases inert gases are used to pressurize the tanks. In this case both tanks containing oxidizer and fuel are pressurized with the help of inert gas it's usually helium. Bigger liquid rocket motor like F1 engine(A2) fitted to Saturn v rocket have turbopumps to injecting fuel and oxidizer at high pressure in combustion chamber. Fuel and oxidizer mixed and burned in the combustion chamber at high pressure as a result large amount of exhaust gas at high temperature and high pressure is created these hot exhaust gas is passed through a nozzle which accelerate the flow and thrust is produced

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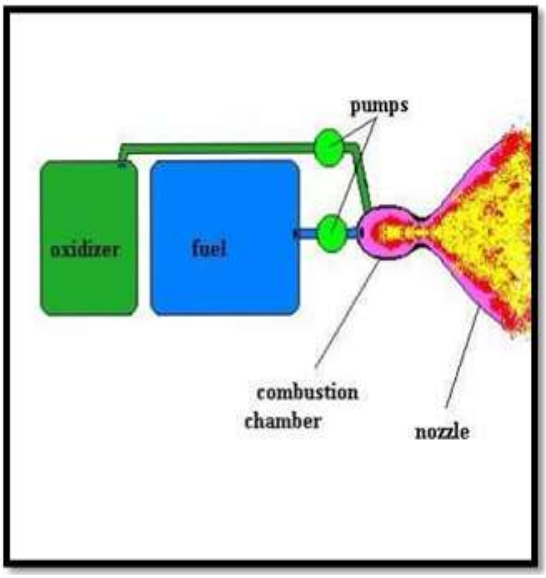

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Rocketdyne F1 engine (A2) **Liquid rocket engine (A1) LIQUID ENGINE CYCLES (A1.1)**

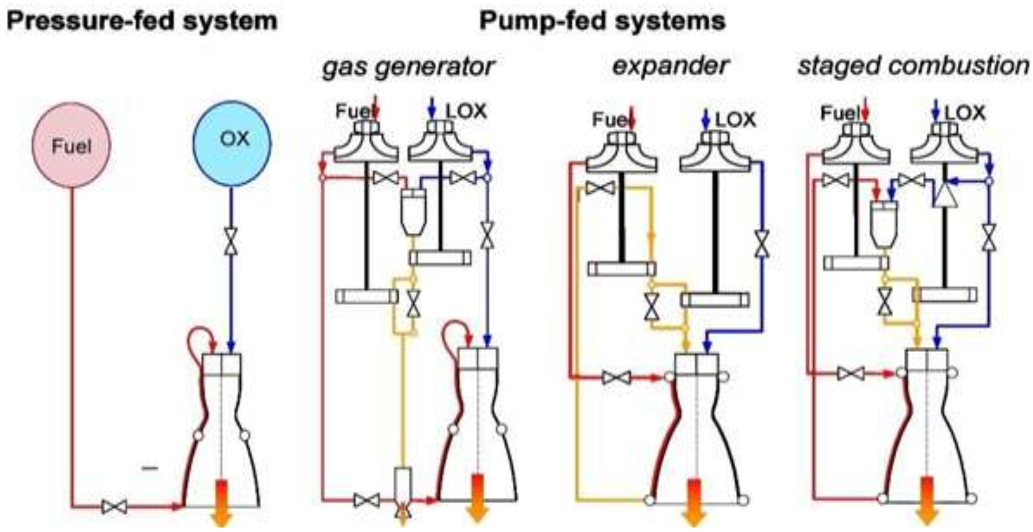
Different engines are classified according to the method of pressurization and transfer of fuel from tanks to the combustion chamber. There are different ways referred as engine cycle. The main two are pressure fed engines and pump fed engines. Pump fed engines further divide into staged combustion, gas fed system and expander.

Pressure fed system (A1.1.1)

Pressure fed system can be of two types self pressured system and pressurized by inert gas. These engines are fairly less complex due to less complicated pressure lines transfer of fuel push through.

Pump fed system (A.1.1.2)

Pump fed systems are more complex than pressure fed system. These engines use turbo pumps to fed the fuel and oxidizer mixture in the combustion chamber with suitable pressure to sustain chamber pressure that helps to create thrust. In these engines some amount of propellant is sent to the a different combustion chamber called as gas generator. These gas generator operate t fairly high temperature around 840k. Then the gas is passed through the turbine which helps



A.1.1.1. A.1.1.2

turbopump to create required propellant pressure. In staged combustion cycle all of the fuel goes through one pre-burner/turbine and all of the oxidizer goes through the other pre-burner/turbine

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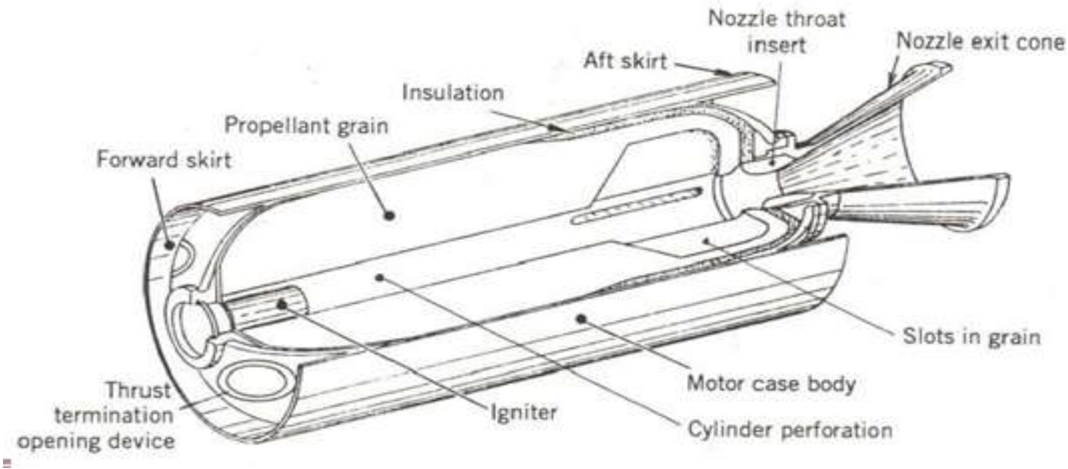
so it arrives in the combustion chamber super pre heated. In expander cycle it lets the fuel evaporate to a gas. Then this gas is used to power the turbine. The exhaust of the turbine then fed to the combustion chamber to be combusted with the oxidizer. It's very efficient because it's a closed cycle.

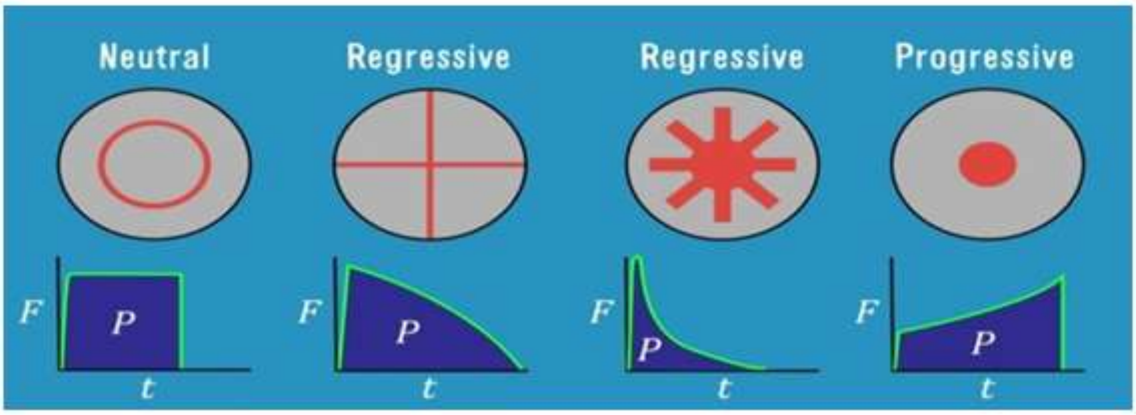
III. LIQUID ENGINE CYCLES

Solid Rocket Motor. A.2.

When we talk about solid chemical propulsion where the fuel and oxidizer are mixed and stored in solid state. When we talk about solid chemical propulsion we use motor. In the motor, the combustion chamber is elongated. For larger motors, it's usually molded or cast in pieces and afterwards assembled. Between the combustion chamber and the propellant lies an insulation layer to protect the combustion from the extreme heat. The simplest shape of the solid propellant is a cylinder with a hole through the middle(A.2.1). The hole is named the perforation. The burning starts on the surface of the perforation and expands outwards. There are many shapes, also known as grains(A.2.2), that the solid propellant can be stored as the surface area of the grain at any instant is proportional to the thrust. This is why different grains have different thrust to time curve as shown below.



Solid Rocket Motor (A.2.1)

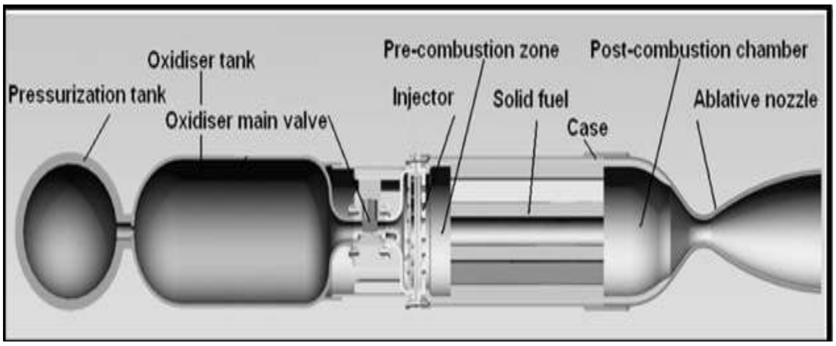


Grains and thrust curve of the solid rocket motor (A.2.2)

In Progressive grains thrust increase over time. Thrust that decrease over time is regassive grain, and constant thrust is neutral. Area under the curve represents movementum gain by burning the propellant.

IV. HYBRID ROCKET MOTOR. A.3.

Hybrid engines use both a solid propellant and a liquid or gaseous propellant .For instance, a solid fuel is stored in the combustion chamber and a liquid oxidizer is added from a tank. Usually it's the fuel that's solid, but it can also be the other way around. The advantage of having a liquid oxidizer is that it's safer and more efficient than having a liquid fuel. A valve is used to control the flow of the oxidizer. The valve controls how fast the oxidizer is allowed to interact with the fuel, meaning that it can control the thrust. Before the liquid propellant enters the chamber, it passes an injector to atomize the liquid, essentially turning it into tiny pieces. This is necessary to get a stable and homogeneous burn without the chaos you would expect of a liquid. The liquid propellant is pushed into the combustion chamber using an inert gas tank or a turbopump system, just as is the case with liquid propulsion. The turbine of such a turbopump system can be powered in a number of ways. A solid rocket motor can be used for instance.



Hybrid Rocket Motor

A bit of an odd application of hybrid engines is the Bloodhound SSC. This vehicle will attempt to reach 1,000 mph, breaking the current land speed record of 763 mph, set by the same group of people in 1997. Here they have a tank carrying about 2100 lbs of hydrogen peroxide. This will act as the oxidizer of the hybrid propulsion system. Notice how there are these perforated walls inside of the tank. Some tankers have these too. They help evenly distribute the force from the sloshing liquid across the wheels. Here we see the oxidizer pump. It will be spinning at about 10,000 RPM. It has 3 inducers at the top which split into 6, then 12 and eventually 24 separate blades.

The pump is driven by a 550 break horsepower supercharged Jaguar V8 engine that can somehow run at 18,000 RPM. Here we see the rather long hybrid motor. Long motors have a high surface area grain that doesn't burn for very long. This results in higher thrust for a shorter period of time. Less burn time is useful because then the drag of the air and wheels doesn't have time to slow down the vehicle as much, so the top speed goes up. The vehicle is also powered by a jet engine which takes it to about 650 mph. A butterfly valve opens allowing the pump to fill up with hydrogen peroxide from the tank. The pump and engine are linked. The clutch is still disengaged. A small amount of hydrogen peroxide now passes the injector and the hybrid engine starts burning. Now the engine racks up from 3,000 to 18,000 RPM. The clutch engages and the pump rapidly accelerates. Now the hybrid motor is at maximum thrust, accelerating the vehicle to 1,000 mph.

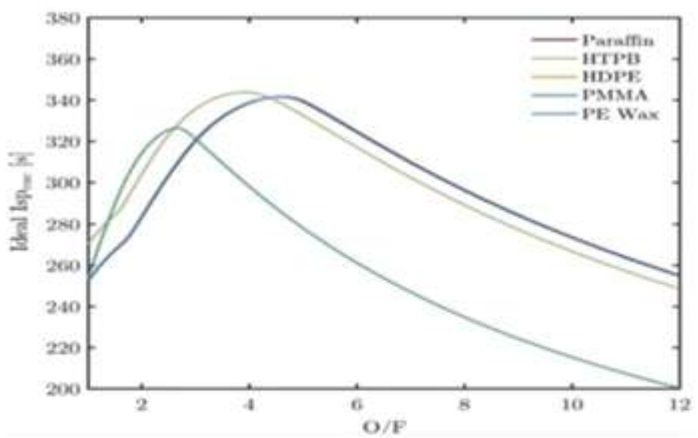
Let's go over the advantages and disadvantages of a hybrid engine. We'll start with the advantages. The valve is used to control the thrust. By closing the valve entirely, the engine can also be shut off completely. Solid rocket propulsion can't do this. Solid and hybrid propulsion can. The manufacturing process of a hybrid propulsion system is safer than that of a solid propulsion system. In solid propulsion, the fuel and oxidizer are mixed. A spark can ignite the propellant.

Here we have a video of the boosters of NASA's Space Launch System being molded. This is a very dangerous process. In hybrid propulsion, the fuel and oxidizer are separate. If the fuel is ignited, it only has the oxygen in the air to burn. The burning is a lot slower, if there is any burning at all. This makes the manufacturing process of hybrid propulsion much safer. Hybrid propulsion is simpler than liquid propulsion, but more complex than solid propulsion. The cost lies somewhere between those of solid and liquid propulsion. Now the, solid fuels tend to be denser than liquid fuels. Let's take a look at some examples of fuel densities.

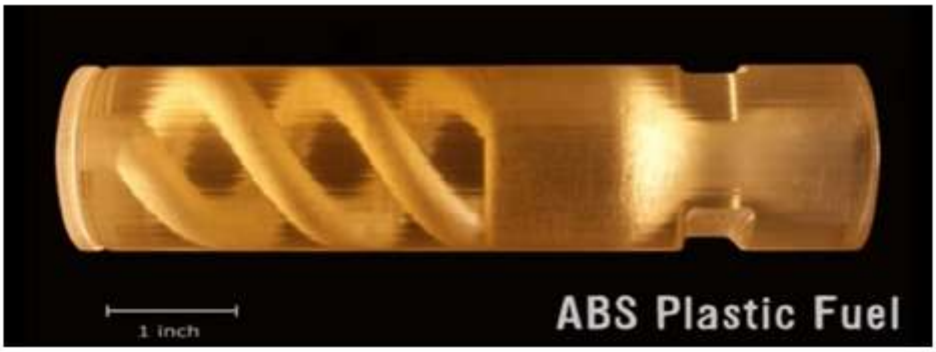
Fuel density of Solid fuel
1. ABS: 1.07 g/cm³
2. CH12H22011: 1.59 g/cm³
3. Gunpowder: 1.7 g/cm³ 4. TP-H1148: 1.758 g/cm³

Fuel density of Liquid fuel
1. N2H4: 1.02 g/cm³
2. RP-1: 0.81 g/cm³
3. UDMH: 0.793 g/cm³
4. CH4: 0.656 g/cm³

In model rocketry sucrose sugar is often used as a fuel, which has a density of about 1.59 grams per cubic centimeter. The most popular liquid fuel is RP-1. It's a sort of refined petroleum very similar to jet fuel. This one's density is merely 0.81 grams per cubic centimeter. Other liquid fuels like liquid methane, which is getting some popularity and liquid hydrogen are much less dense still. Hybrid propulsion takes up less space than liquid propulsion does due to the higher density of the fuels. This is a major advantage. Hybrid propulsion can be very efficient. Much more efficient than solid propulsion. This is because the most efficient oxidizers are the liquid ones. Primarily liquid oxygen, but also liquid fluorine. In solid propulsion the oxygen is bonded to other atoms so that it remains a solid, which results in a loss in efficiency. For example, in model rocketry potassium nitrate is used as the oxidizer and sucrose sugar as the fuel. Three oxygen atoms are bonded to a nitrogen and a potassium atom. The additional potassium and nitrogen atoms are required to keep the material solid. In liquid propulsion there's no need for these additional atoms. Take liquid hydrogen fuel and liquid oxygen oxidizer, for instance. The oxidizer is just the oxygen in liquid form. The efficiency, just as the cost, typically lies between solid and liquid propulsion. As a reminder, by a high efficiency we mean a high velocity of the exhaust gas. The efficiency does vary a lot depending on the mixture ratio, meaning the fuel to oxidizer ratio. When the mixture ratio is far from ideal for the reaction, so when the system is throttled down significantly using the valve, the efficiency is low. We can see this on the graph.



Along the horizontal axis we have the mixture ratio. When it is very low, so on the left side, the efficiency is also low. Also notice how different fuels have different curves. The grains used in hybrid propulsion tend to be quite complicated. The result is that some of the solid propellant is usually left unburnt. This is unfortunate, because that unburnt propellant would have resulted in significant acceleration since the mass is low at engine cutoff. The best hybrid propulsion grains are borderline impossible to mold. 3D-printing does allow to make them, but then size and fuel choice become a problem. Still, the technology might see large-scale application in the future as 3D-printing advances. So, here is a picture of a transparent 3D-printed grain.



V. 3D PRINTED GRAIN

It uses a sort of double helix design which has a large surface area, so a high thrust, but still consists of very little empty space, so it has a high density as well. High thrust and high density make it ideal, but it's clearly not feasible to mold. The Space Ship One aircraft was the first privately funded program to get a human to space. It was able to carry 3 people. Space Ship One attached to another aircraft called White Knight One to lift off. At 50,000 feet, the two separated.

Space Ship One would use a hybrid engine to get to space, which is defined as 100 kilometers altitude. Both Space Ship One and White Knight One were able to land and be rapidly reused. About a month ago as of this video, a newer version of this aircraft called VSS Unity had a successful test flight. Virgin Galactic, the company now developing it, wants to use it to take customers on trips to space. After detaching from VMS Eve, VSS Unity reached a speed of 1,400 mph in about 30 seconds.

As of now we know the advantages and disadvantages of hybrid Rocket propulsion and development in this space is promising. As we move forward we will have more efficient hybrid Rocket and safer, consistent results.

VI. CONCLUSION

In this paper we learned how the hybrid propulsion system works and it's advantages some of difficulties that comes with this design in simple language. How this rocket technology seems complicated but it's just a simple rocket designed with existing liquid and solid technology. Hybrid Rocket propulsion is in between liquid and solid rocket. But more enhancement can be game changing in this field.

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