

# STUDY OF CRYOGENIC ROCKET ENGINE

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## ABSTRACT

*This paper is all about Cryogenic Technology used in rocket's engine for all its space missions & its applications. This technology consists of use of two basic elements of universe Liq. Hydrogen(-253°C) & Liq. Oxygen(-183°C). This engine follows Newton's basic 3<sup>rd</sup> law of motion. This is the only engine that gives 100% efficiency without any green house emissions or pollution up to the date on earth. This engine gives a thrust of 15000 lb. when basic methods are used. This thrust can be increased to great extent if research in proper field is done.*

*When these fuels are mixed at their cryogenic temperatures they give out huge energy which is can be utilised to:*

- *Take off of a Space vehicle its escape velocity.*
- *Launch a missile across continents.*
- *Generate electric energy.*

**Keyword : Rocket engine, Cryogenic technology, Cryogenic temperature, Liquid hydrogen and oxygen, Newton's third law of mechanics.**

## I. INTRODUCTION

Cryogenic Technology which mainly deals with temperatures below -150 C is the main working principle behind the cryogenic engines. When elements cooled at these temperatures they change their properties. Same is the case with one used in rocket engines when oxygen is cooled below -183 degree centigrade it changes its state to liquid & its properties, similarly when hydrogen is cooled below -253 degree centigrade.

During these temperatures when these liquid are clashed against in a controlled condition in a combustion chamber it gives a huge thrust which has a specific impulse of near about 450. No other engine can. Generate this amount of energy in negligible amount of fuel. Since its invention in USA is used in all space mission by every country due to its reliability. Cooling used for thrust chamber during combustion is also provided by liquid fuel which saves a lot of energy used for cooling[].

As compared to other fossil fuel the cryogenic fuel requirement is far less to produce same amount of energy.

## II. HISTORY OF TECHNOLOGY

This Rocket Technology has a great History involving many giant nations including USA, Russia, Japan, France etc. A close competition was lead in later half of 20<sup>th</sup> Century for this technology since its invention by USA. When USA successfully launched its 1<sup>st</sup> Atlas V rocket in 1963 boosted up the cold war between between Russia & USA which played a great role in rapid advancement in this technology in such a short period of time.

After USA Russia started it's tests of launch vehicles. Firstly Russia carried a dog named 'Lynus' in space in 1983. Russia was first to take human in space using sputnik.

During this period lot of European countries were trying their rockets with same technologies & succeeded later, But no human being till 1985.

Here's the detail review of the competition

<b>Engine/Rocket used</b>	<b>Nation</b>	<b>Year</b>
<b>RL-10</b>	<b>USA</b>	<b>1963</b>
<b>LE5</b>	<b>Japan</b>	<b>1977</b>
<b>HM7</b>	<b>France</b>	<b>1979</b>
<b>N1</b>	<b>Russia</b>	<b>1983</b>
<b>GSLV-D5</b>	<b>India</b>	<b>2013</b>

### **2.1. India**

Indian Space Research Organisation was also trying it's hand on this technology in 20<sup>th</sup> Century. ISRO's then Chairman U.R.Rao in 1993 announced that it's Cryogenic engine will have a launch in just 4 years. But it took more than 20 years to Ignite it's Cryogenic Engine so we joined the competition much late in 21<sup>st</sup> Century due to its frequent failure & no technological support from other developed Countries.

But now ISRO is working good with successful launch of Mangalyaan in it's first attempt, being the first country of this kind.

### **III.CONSTRUCTION**

Cryogenic Engine involves:

- I. Two Tanks for Liq. Oxygen & Liq. Hydrogen respectively.
- II. A turbo Pump.
- III. A Gas generator.
- IV. A Combustion chamber.
- V. A nozzle with a cooling jacket.

In this setup a turbo pump is used to give a high velocity to the fines droplets of fuel in combustion chamber. A gas generator is used to drive the turbo pump. Gas generator uses the energy from fuel to generate energy for turbo pump.

## **IV. WORKING**

### **4.1. Gas Generator**

The gas generator is used in order to drive the turbo by a gas flow. The gas generated produces this energy by pre burning some amount of liq. Fuel. Use of Gas generator aligned with Turbo pump increases the efficiency of this engine to a great Extent

### **4.2. Turbo Pumps**

The working of this engine is very easy to understand as it does not involve any complicated cycles or any reciprocating mechanism. The fuel from tanks is firstly passed through the turbo pumps which rotates at a speed of about 14000 rpm by which the mass flow rate of fuel increases to about 2.4 tons before reaching the combustion chamber.

### **4.3. Injector**

Injector plays the most important role in the rocket engine it is like heart of the engine that pumps out the appropriate amount of fuel from the turbo pump to the combustion chamber as per requirement. Injector ensures the stability of the combustion chamber therefore deigning of injector is the most challenging part of the designs department of cryogenic engine even today. The frequency of the combustion chamber is to be maintained between 100-500 cycles per second. If this rate is affected even slightly shifted above or below leads to the failure of engine which has been seen in tragedy of 'Discovery Spacecraft'. But if injector is so designed so as to increase the specific impulse more than 700 Space crafts can travel much long distances in the universe. Injector is the only component of this engine which is still under construction yet.

### **4.4. Combustion Chamber**

Finally when this finely distributed fuel droplets enter into the thrust chamber at such high velocities & at their cryogenic temperatures they colloid to each other in the trust chamber, this reaction at such specific conditions increases the pressure of chamber to about 250 bar with a release of huge amount of thrust which is more than 15000 lb.

This high amount of trust is then manipulated by a narrow opening towards the nozzle. The opening is kept narrow so as to follow law of rate of discharge which states that 'velocity is inversely proportional to area'. By this technique we get the desirable amount of thrust which helps a space craft to achieve it's escape velocity.

Due this reaction in continues period of time the temperature of Combustion Chamber as well as nozzle raises up to 3000-4000°C. To withstand such a high temperature for long period of time without any deformation a cooling Jacket is required.

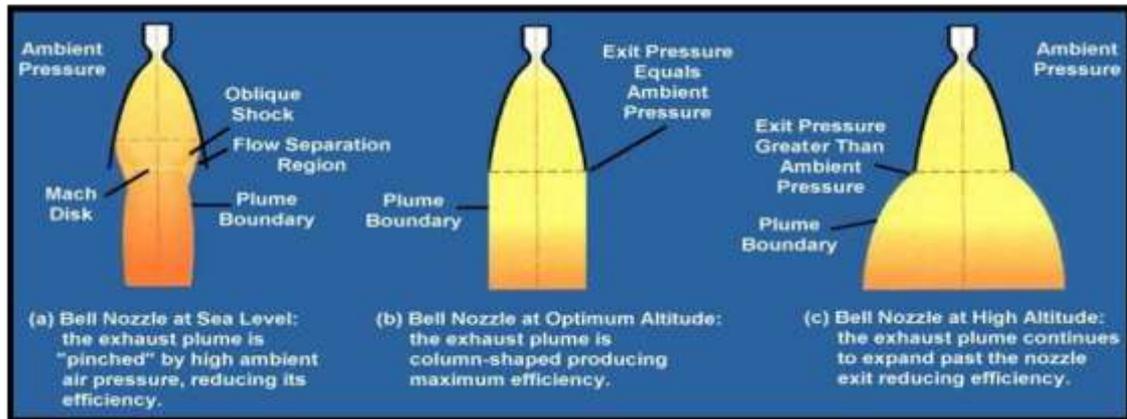
### **4.5. Cooling Jacket**

Cooling Jacket is the necessity of this engine but this facility is provided by the fuel of the engine itself so no external energy is to be used. The mechanism usually used in cooling jackets is active cooling.<sup>[6]</sup> In this Technique the cooling jacket is made such that a flow of liq. Proponents is passed through the tubes provided from between the jackets. The liq. propellant passed are already at their cryogenic temperature so provide a very effective cooling. This simple mechanism permits the Use of this technology throughout it's journey without any deformation in Combustion chamber or Nozzle.

When all these components work in their perfect algorithm, only then we can achieve our goal a successful launch of a space vehicle for it's space mission.

#### 4.6. Plume characteristics

After the reaction in trust chamber Tremendous amount of energy comes from the nozzle through the small opening in the form of plumes. These plumes have a very high temperature during their emissions. Therefore nozzle is also provided with cooling jacket. As the rocket heads from ground the shape of plumes also changes with respect to height achieved by the rocket



**Fig. 4.6.1**

When the height of rocket is near to sea altitude the ambient pressure acting on rocket & in directly on engine is more, hence more energy is required to overcome it, so the plume area is less than nozzle diameter at this altitude also efficiency is less.

When the Rocket advances to a optimum altitude the plume boundary equals the diameter of nozzle that means ambient pressure equals exhaust pressure. Therefore maximum efficiency is achieved i.e. 100% this phase gives full efficiency which is only possible in cryogenic engine. After heading this altitude the rocket advances toward vacuum environmental, this area gives optimum efficiency near about 88% which remain constant here onwards.

#### V ADVANTAGES

- 1) High Energy per unit mass Propellants like LOX and LH<sub>2</sub> give very high amounts of energy per unit mass.
- 2) Clean Fuels: Their product give out only water thrown out of the nozzle in the form of very hot vapour.
- 3) Economical: LOX & LH<sub>2</sub> costs less than gasoline.

#### VI DISADVANTAGES

- 1) Boil off rate
- 2) High reactive gases
- 3) Leakage
- 4) Hydrogen embrittlement
- 5) Zero gravity condition

## VII. FUTURE SCOPE

Being the most reliable engine & its use in all space missions a lot of advancement in this technology is made every day. This technology involves fuel which cheaper than even fossil fuel therefore this technology can give humans safe & reliable technology in near futures. Generally any rocket engine burns their respective fuels to generate the thrust<sub>[4]</sub>. If any other engine has capacity to generate thrust efficiently then it can be called rocket engine.

Currently NASA scientists are working on 'Xenon Ion Engine' which accelerates the ions or atomic particles to extremely high to create thrust more effectively and efficiently by usage of electrostatic or electromagnetic force by the principle of Lorentz force or Columbian force. In this technology ions are powered towards the anion at a speed of 30 km per second

## VIII. CONCLUSION

Cryogenic Rocket Engine is a simple engine based on laws of Cryogenic science & Newton's 3<sup>rd</sup> law of motion. Cryogenic Technology ensures the stability of fuel & by following Newton's 3<sup>rd</sup> law the thrust is generated. These two principles work hand in hand to make this engine a mega success of 20<sup>th</sup> & 21<sup>st</sup> Century. Also while comparing Rocket engine with jet engine, thrust produced in rocket engine is outwards and that in the jet engine is inwards. Hence this efficiency cannot be achieved by any other engine.

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