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A REVIEW ON CRYOGENIC ROCKET ENGINE

Swapnil Agrawal[1] & Megha Kolhe[2]

[1]Assistant Professor, Dept. of Mechanical Engineering, Mauli Group Of Institution College Of Engineering and Technology, Shegaon , Maharashtra ,(India)

[2]Student, Dept. of Mechanical Engineering , Mauli Group Of Institution College Of Engineering and Technology, Shegaon , Maharashtra ,(India)

ABSTRACT

Cryogenic treatment is a material science and involves the process of reducing the temperature of component over an extended period of time to extreme cold levels, usually slightly below -250°C. Cryogenic engines are commonly used in rockets for launching geosynchronous class satellites This paper is all about Cryogenic Technology used in rocket's engine for all its space missions & its applications. This technology use liquid fuels that are cooled to very low temperatures and which would otherwise be in gaseous state at normal atmospheric pressure and temperature, such as hydrogen and oxygen. These fuels are use in such a way that to produce high amount of propellant force. Either the hydrogen is vaporized as the fuel and ignited by the oxidizer of that exits the engine nozzle and creates thrust .it consists of use of two basic elements of universe oxygen to generate standard hot rocket thrust, or they are mixed to create super hot stream Liq. Hydrogen(-253°C) &Liq. Oxygen (-183°C). This engine follows Newton's basic 3rd law of motion. As per this mechanism .the thrust produced in rocket engine is outwards whereas that produced in jet engine is inwards. This rocket engine is gives 100% efficiency without emitting any harmful gases to environment.

Keywords: *Cryogenic engines, geosynchronous class satellites, Cryogenic Technology, liquid Hydrogen and Oxygen, Newton's basic 3rd law of motion.*

I. INTRODUCTION

Cryogenic originated from two Greek word "Kyros" which means cold or freezing "gene" which means burn or produced, however the term is used as today as a synonym for the low temperature. It is not well defined at the point on this temperature scale refrigeration end and Cryogenics begins. Cryogenic is the study of production of very low temperature nearly about '123 k' in which the material behavior and properties are studied at that temperature. Cryogenics typically involves a deep freezing process, usually one that takes object down below 240°F and changes molecular alignment of the material structure. This change creates the new property. Cryogenic engine is a rocket engine in which liquid fuel or oxidizer used. These fuel and oxidizer remains in liquid state by the process of refrigeration. Liquid fuel are burn to produce hot reaction gas product, this hot gas product are accelerated and ejected at supersonic velocity by nozzle. Payload capacity of the space vehicle can be increased with the propulsion conventional solid rocket engine which results in higher specific impulse.

Types of cryogenic treatment

1. Shallow Cryogenics, made the objects to temperature of approximately 1200°F.
2. Flooding, flooding is done with liquid Nitrogen and makes the components upto -1200^{0}F
3. Deep Cryogenics Treatment, is the treatment make that the component approximately -3000°F.

II. HISTORY OF TECHNOLOGY

The only claim to liquid propellant rocket engine experiments in the nineteenth century was made by a Peruvian scientist named Pedro Paulet. However, he did not immediately publish his work. In 1927 he claimed that he experimented a liquid rocket engine three decades earlier when he was a student. Many giant nations like USA, Russia, Japan, France etc has involvement of this rocket technology. Since its invention by USA this technology

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faced competition. This technology had vital role which boosted up the cold war in 1963 when USA launched its 1st Atlas V rocket followed by USA, RUSSIA, also started testing of launched vehicles. Initially Russia carried a dog named linus in space in 1983. Russia was first nation to take human in space using sputnik at the were also testing their rocket with this Technology in which they succeeded. During this period lot of European countries were trying their rockets with same technologies & succeeded later [14].

III. CRYOGENIC TECHNOLOGY

A cryogenic technology is uses the rocket propellants their at a cryogenic temperature i.e rocket propellants in cryogenic technology in liquid state. Propellants can be combination of liquid fuel such as, liquid oxygen (LOX), used as oxidizer and liquid hydrogen (LH2) as fuel. This combination can be use in different mixture or in different proportions. The mixture of liquid hydrogen and liquid oxygen gives highest energy efficiency and produces very high amount of thrust for rocket engine. These fuels are gaseous in normal atmospheric conditions, to obtain these propellants in liquid state it must be refrigerated upto their cryogenic temperatures. Here, Hydrogen is use below (-253^{o} C) and oxygen at below (-183^{o}C). Sometimes this engine uses liquid Nitrogen (LN2) as fuel and its exhaust gas is also nitrogen. Liquid oxygen supplied to the engine below critical temperature but above critical pressure.Nitrogen are present in atmosphere is about 78% And is non-pollutant gas and is not produced any harmful gas during exhaust. Hence engine have high efficiency than any jet engines.

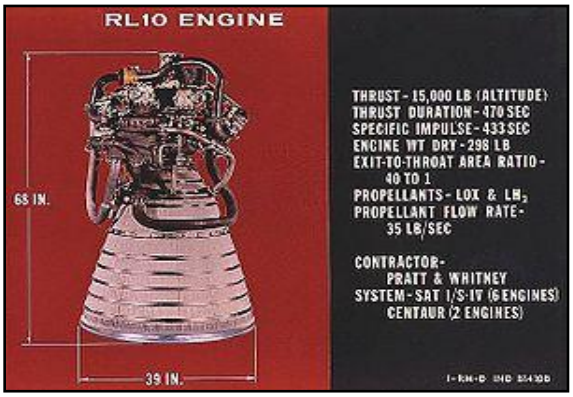

Fig1: RL-10 engine

3.1 Why does the need to liquefy gases arise?

A primary fuel such as hydrogen is burn with the help of oxidizer which g he a huge amount of energy causes rapid expansion of gases which result in high pressure. The nozzle is design to convert pressure energy of gas into kinetic energy. When the exhaust gas is passed through it. Thehigh mass flow rate of both fuel and oxidizer are required to generate high thrust at a greater efficiency. Gases and liquid are differentiated by their intermolecular separation of atom.So volumetric difference occurs in liquid state and gaseous state. Therefore in a given volume of both states. Liquid state hasmore mass of fuel as compare to gaseous state. For the improvement of propulsion system, both fuel and oxidizer use in their liquid state. The advantage of using liquid propellant is that, it consume low pumping energy for higher mass flow rate and consume lower space for storage as compared to gaseous state. As we know, rocket is works in stages and required less weight for the better working engine. Oxygen and hydrogen occurs in gaseous form in normal atmospheric condition and is require special pressurized container to store. Hence it is better to convert these fuel and oxidizer into liquid form.

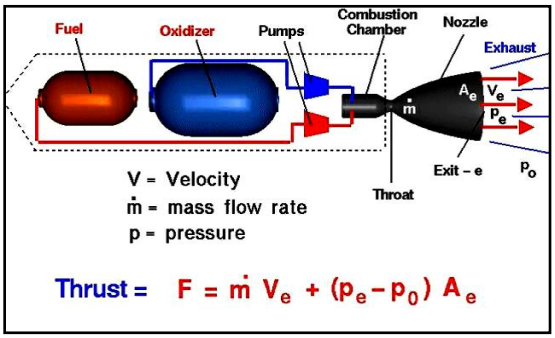

Fig 2. Construction of Engine

IV. CONSTRUCTION

RL-10 CRE engine shown in fig 1.his engine uses the complicated staged combustion cycle. turbine, pumps, gas generator, turbo pump,thrust chambers and nozzle are the important parts used to increase engine efficiency and they are describe below:-

1. Gas generator:- It delivers sufficient amount of driver gas at designed temperature and pressure which generates propellant supply of thrust chamber

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2.Turbo pumps:- They receive liquid propellant at low pressure from tanks and supply to combustion chamber.

3.Thrust chamber:- Thrust is generating by conversion of chemical energy in to gases kinetic energy. In this combustion liquid propellants in combustion chamber through the nozzles which are converging/diverging sections.

4.Nozzles:- The pressure generated in combustion chamber can be used to increase the thrust by acceleration of combustion gas. At constant pressure,1 dimensional ideal gas flow thrust equation is given as:

$$F= m\ ue+ (Pe - P\infty)\ Ae$$

Where-

Ue is exhaust gas value at exist area.
Ae and Pe is respective pressure and area
P∞ is ambient pressure

Why high efficiency?

According to Newtonian third law of mechanics: 'Action and Reaction are equal and opposite in direction'. Rocket engine operates through force of its exhaust pushing it backwards. Thrust is in opposite direction and more efficient in lower atmosphere or vacuum (sometimes). It makes the use of liquid oxygen as an oxidizer and liquid hydrogen as fuel. Pure liquid oxygen as oxidizer operates significantly at hotter combustion chambers due to which extremely high heat fluxes are produced which is not available in any jet engines. In jet engines petrol, diesel, kerosene, gasoline, LPG, CNG and PNG, etc., are used having the properties of hydrocarbons

Rocket engine power cycles

Basically rocket engine works on mainly three power cycles, which are as follows

1. Gas pressure feed system
2. Gas Generator cycle
3. Staged Combustion Cycle

1 . Gas pressure feed system

This system consists of high pressure gas tank, a gas starting valve, a pressure regulator, propellant tanks, propellant valves, and feed lines. After all tank are filled, the high pressure gas valve is remotely actuated and admits gas

through the pressure regulator at a constant pressure regulator at a constant pressure to the propellant tanks. The check valves prevent mixing of the oxidizer with the fuel when the unit is not in an right position. The propellants are fed to the thrust chamber by opening valves. When the propellants are completely consumed, the pressurizing can also scavenge and clean lines and valves of much of the liquid propellant residue. The variation in this system, such as the combination of several valves into one or the elimination and addition of certain components, depend to a large extent on the application. If a unit is to be used and over, such as space-maneuver rocket, I will include several additional features such as possibly, a thrust regulating device and a tank level gauge.

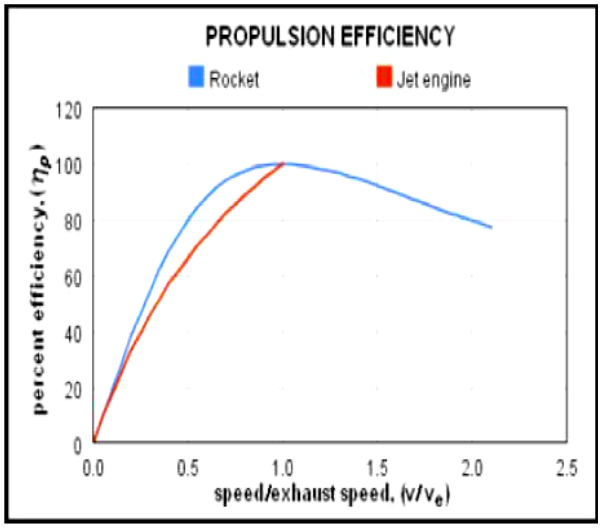

Fig3: Propulsion Efficiency

2. Gas Generator cycle

The gas generator cycle taps off a small amount of fuel and oxidizer from the main flow the main flow to feed a burner called gas generator. The hot gas from this generator passes through a turbine to generate power for the pumps that send propellants to the combustion chamber.The hot gas is then either dumped overboard or send into the main nozzle downstream. Increasing the flow of propellants into the gas generator increases the speed of turbine, which increases the flow of propellants into the main combustion chamber. The gas generator must burn propellants at a less than optimal mixture ratio to keep the temperature low for the turbine blades. Thus, the cycle is appropriate for moderate power requirements but not high power systems, which would have to divert a large portion of the main flow to the less efficient gas generator flow.

3. Staged Combustion Cycle

In a staged combustion cycle, the propellants are burned in stages.like the gas generator cycle, this cycle is also has a burner,called a pre-burner ,to generate gas for a turbine. The pre-burner tap off and burn a small amount of one propellants and a large amount of the other, producing an oxidizer-rich or fuel-rich or hot gas mixture that is mostly unburned vaporized propellant. This hot gas is then passed through the turbine, injected into the main chamber, and burned again the remaining propellants are burned at the optimal mixture ratio in the main chamber and no flow is dumped overboard. The staged combustion cycle is often used for high-power applications. The higher the chamber pressure, the smaller and lighter the engine can be to produce the same thrust. Development cost for this cycle is higher because the high pressures complete the development process.

V. WORKING

Cryogenic Engines are the engine which uses the cryogenic Technology. Mostly liquid oxygen (LOX) and liquid hydrogen (LH2) are use as oxidizer and fuel respectively. Basically oxygen and hydrogen exists in gaseous forms at normal pressure and temperature. Hydrogen and oxygen are uses in their liquid state, hence it need to maintain at

their cryogenic temperature i.e hydrogen is at below 20°K and oxygen is below 90°K.This refrigerated fuel are stored in insulating cylinder to maintain it in liquid state. Engine components are no hot, it is cold. Hence, there is no chance of conversion of liquid into gas. This fuel are burn in combustion chamber and exhaust gas given to the turbine, in which rapid expansion of hot gas is done and power is developed therefore motor runs with high speed. By considering all parameter, efficiency of rocket engine is high but weight is main disadvantage.

Currently, only six countries are successful to developed cryogenic rocket engines that are United States, Russia, China, France, Japan and India. This engine are used to lift the satellite. This process of reducing the temperature of component over an extended period of time o extreme cold level, usually slightly below -250°C. Cryogenic engine are commonly used in rockets for launching geosynchronous class satellites and for all its space mission and its application.

The cryogenic engine have this name from their working, in which liquid propellants are used. Including oxygen and hydrogen, liquid Nitrogen can be used at extremely cold temperature. Free air flows around vehicle, air get heated by the heat of engine. This hot air are used to heat the Nitrogen and conversion of liquid Nitrogen into gas are take place just like in steam engine in which water forms steam to developed power. In rocket engine liquid oxygen and hydrogen are used. The liquid nitrogen are stored at -320 degrees Fahrenheit, for working operation. Nitrogen having tendency to expand 700 times the its liquid states volume

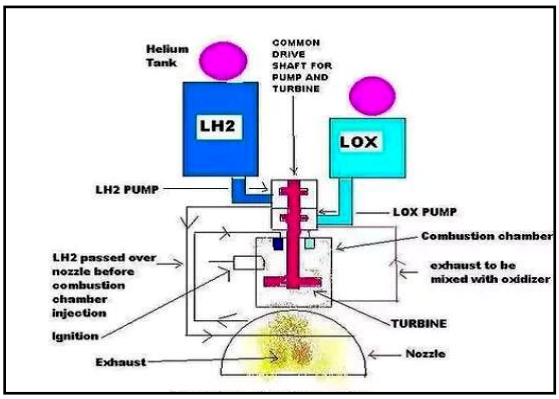

Fig 4: Working of Engine

VI. NEXT GENERATION OF ROCKET ENGINE

Generally, To generate high thrust engine burn the suitable fuel, such engine are known as rocket engine. If the engine having the capacity to generate sufficient amount thrust then the engine known as rocket engine. Currently NASA scientists are working on Xenon Ion Engine' which accelerates the ions or atomic particles to extremely high create thrust more effectively and efficiently by usage of electrostatic force or electromagnetic force on the principle of Lorentz force or Columbian force. In this Technology ions are powered at a speed of 30 km per second towards the anion.

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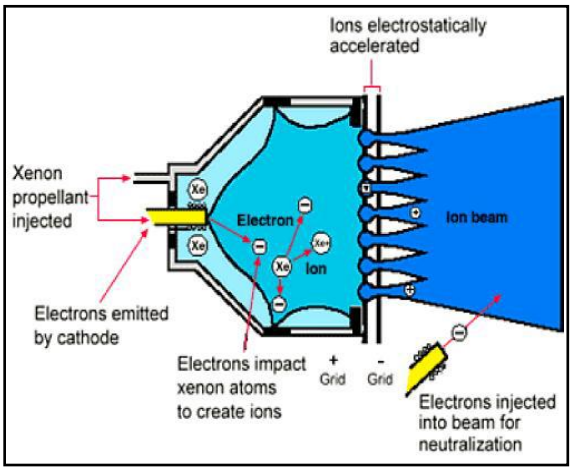

Fig 4: Xenon Ion Engine

VII. ADVANTAGE

1. High Energy per unit mass

Propellants like oxygen and hydrogen in liquid form give very high amounts of energy per unitmass due to which the amount of fuel to be carried aboard the rockets decreases

2. Clean Fuels

Hydrogen and oxygen are extremely clean fuels. When they combine, they give out only water.The water vapour is thrown by the nozzle which does not affect the environment.

3. Economical

oxygen and hydrogen are present in environment in high amount compare with gasoline. Hence oxygen and hydrogen are cheaper than gasoline.

VIII. DISADVANTAGES

1. Low density of liquid Hydrogen-More structural mass.
2. Low temperature of propellants -Complex storage.
3. Transfer systems and operations.
4. Hazards related to cryogens.
5. Overall cost of propellants relatively high
6. Need for ignition system.

IX. CONCLUSION

Cryogenic rocket engine is based on " NEWTON'S 3 rd LAW OF MOTION" which stated as "Everyaction get equal and opposite reaction" From this we can conclude that, Thrust produce in jet engine is inward and in cryogenic engine is outward. Hence the efficiency of rocket engine is high as compare to any other engine. The liquid propellants used in rocket engine is clean fuel and when it combine it throws hot water vapour in environment and which is very economical.

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