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Research Paper

CRYOGENIC ROCKET ENGINE

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This paper is all about the rocket engine involving the use of cryogenic technology at a cryogenic temperature (123 K). This basically uses the liquid oxygen and liquid hydrogen as an oxidizer and fuel, which are very clean and non-pollutant fuels compared to other hydrocarbon fuels like: Petrol, Diesel, Gasoline, LPG, CNG, etc., sometimes, liquid nitrogen is also used as an fuel. The efficiency of the rocket engine is more than the jet engine. As per the Newton's third law of mechanics, the thrust produced in rocket engine is outwards whereas that produced in jet engine is inwards.

Keywords: Rocket engine, Cryogenic technology, Cryogenic temperature, Liquid hydrogen and oxygen, Newtonion's third law of mechanics

INTRODUCTION

Mechanical engineering is totally based upon the laws of physics, Engineering-Mechanics, and Mathematics. Cryogenics is the study of production of very low temperature nearly about '123K' in which the material's behavior and properties are studied at that temperature. Cryogenic rocket engine is a type of rocket engine designed to use the fuel or oxidizer which must be refrigerated to remain in liquid state.

HISTORY OF CRYOGENIC ROCKET ENGINE

In 1963, United States of America was the first country to develop the CRE with the use of RL-10 engines with the successful flight and it is still used on Atlas-V rocket. Other countries are like: Japan used LE5 in 1997, France used HM_7 in 1979 used the respective rocket engines. Here the mixture of liquid N_2, H_2 and O_2 are used as fuels. In 1987, first CRE was launched with human in space.

CRYOGENIC TECHNOLOGY

A cryogenic technology is the process of involvement or including of usage of rocket propellants at a cryogenic temperature. It can be the combination of liquid fuels such as: Liquid Oxygen (LOX), and liquid hydrogen (LH_2) as an oxidizer and fuel in the different mixtures or proportions. The mixture of fuels

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Figure 1: ATLAS-V Rocket

offers the highest energy efficiency for the rocket engines that produces very high amount of thrust. Here, the oxygen remains liquid only at the temperature below (–183 C) and hydrogen at below (–253 C). This is a type of rocket engine that is functionally designed to use the oxidizer which must be refrigerated in the liquid state. Sometimes, the liquid nitrogen (LN_2) is sometimes used as a fuel because the exhaust is also nitrogen. Liquid oxygen is injected below critical temperature but above critical pressure. In our atmosphere nitrogen is nearly about 78%. Nitrogen is a non pollutant gas and during exhaust no other harmful gases are produced. Hence its efficiency is very high than any other Jet engines.

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

Figure 2: Propulsion Efficiency Curve

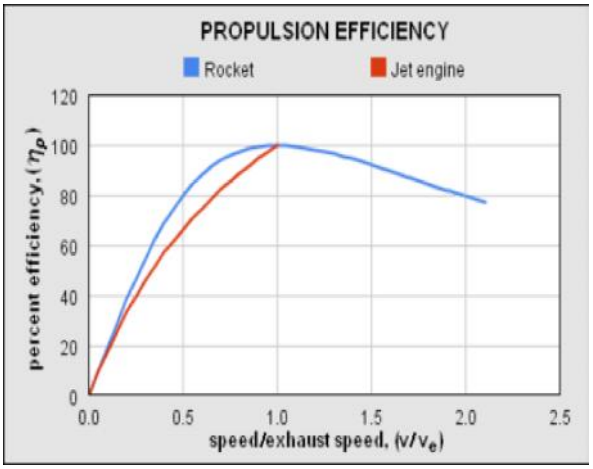


Figure 3: Details of RL-10 Cryogenic Rocket Engine

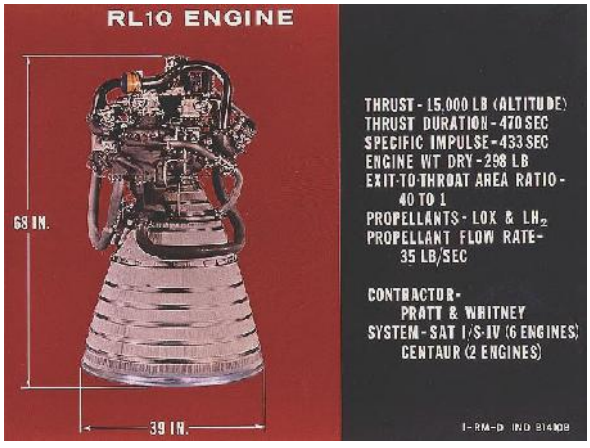
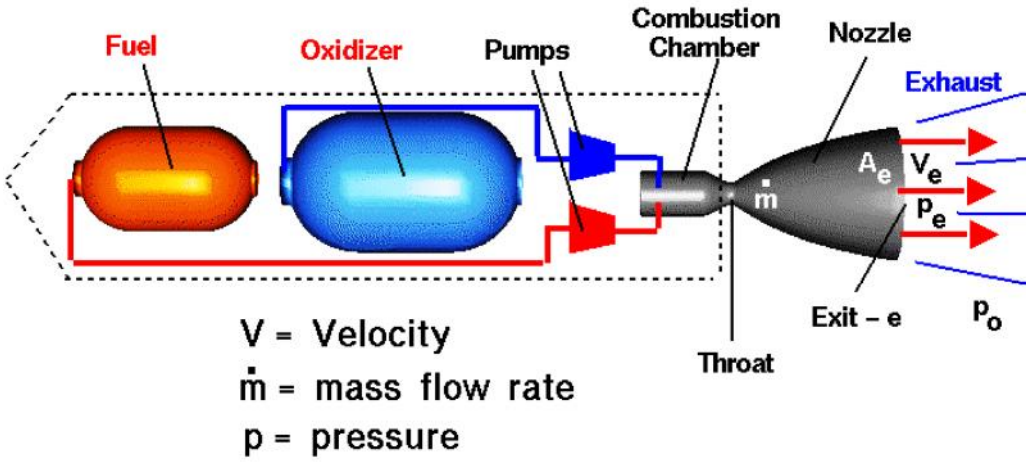


Figure 4: Liquid Rocket Engine



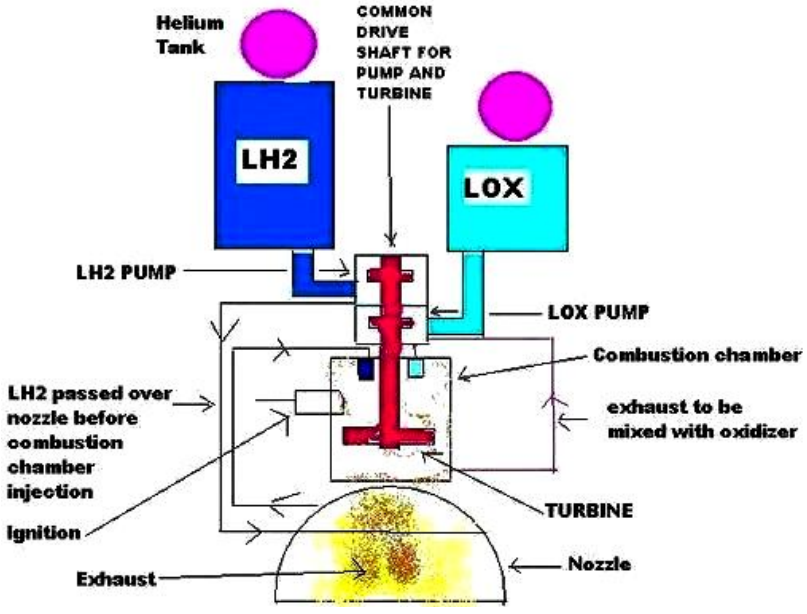
petrol, diesel, kerosene, gasoline, LPG, CNG and PNG, etc., are used having the properties of hydrocarbons.

CONSTRUCTION AND WORKING

Figure shows an RL-10 CRE which involve the complicated staged combustion cycle for Increasing engine efficiency the important parts are listed below: turbine, pumps, gas generator, Propellant injection system, thrust chambers (combustion chamber + short part of divergent section of nozzle). The description of each part with function is explained below:

Gas Generator: The main function of gas generator is delivery of sufficient amount of

Figure 5: Complicated Staged Combustion Engine for Increasing Efficiency



driver gas at designed temperature a pressure which generates continuous propellant supply of thrust chamber.

Turbo Pumps: They receive liquid propellants at low pressure from vehicle tanks which are then supplied to the combustion chamber. Generally, radial and axial turbines are used.

Pump: In simple words, pump adds energy to propellants through the rotation. The material used for all the turbo machinery chambers are: Al alloys, H.S.S, S.S, and Ni-Ti-Co based alloys.

Thrust Chamber: Thrust is generated in thrust chamber by the efficiency conversion of Chemical energy in to gases kinetic energy This can be obtain by combustion of liquid propellants. In the combustion chamber followed by the acceleration of hot gases throw conversion/diversion section of nozzle to acquire high gas velocities and hands thrust.

Nozzle: The pressure generated in combustion chamber can be used increased thrust by acceleration of combustion gas to high supersonic velocity. Nozzle generally passes parabolic enters. (Because when high velocities gases entrance and at exit of nozzle, pressure of exhaust gas increases with high value and hence velocity and hence velocities reduces).

The thrust equation of 1D-flows of ideal gas at constant pressure is:

$$F = mu_e + (P_e - P_{ã}) A_e$$

where: U_e is exhaust gas value at exist area.

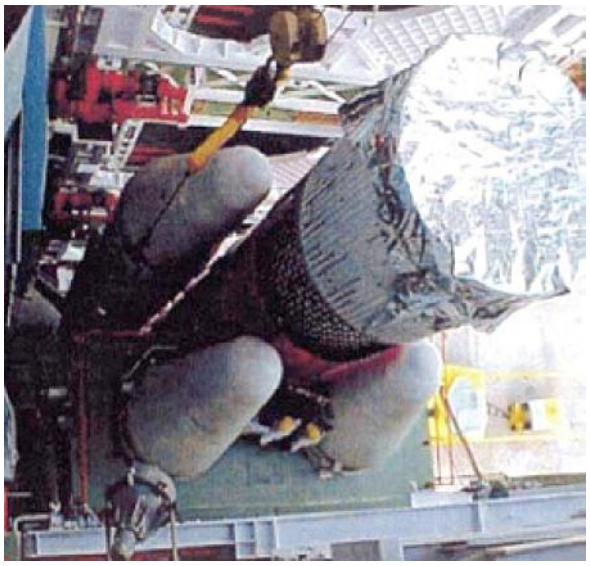
A_e and P_e is respective pressure and area.

$P_{ã}$ is ambient pressure.

MANUFACTURING PROCESS

The Indian CRE is produced by Godrej and Hyderabad based MTAR technology.

Figure 6: Manufacturing of Rocket Engine



WHY DIDN'T CRYOGENIC ENGINE OF INDIA IGNITE?

GSLV-D_3 Rocket engine of India lifted off from Sriharikota on April 15, 2010, Thursday later plunged into Bay of Bengal and failed in ignite. As per the plan, vehicle lifted off at 4:27 pm and its performance as normal up to end of its second stage till 298 seconds from lift off. As ISRO official said: "It is very that very clear cryogenic engine didn't ignite when you look at curve of vehicles trajectory." Vehicle develop problems when cryogenic upper stage would have ignited 304 seconds after the lift off and it fail into Bay of Bengal.

PROS

1. High energy per unit mass
2. Clean fuels
3. Economical

Figure 7: Ignition of GSLV-D_3 Rocket Engine on April 10 – Thursday at Sriharikota

CONS

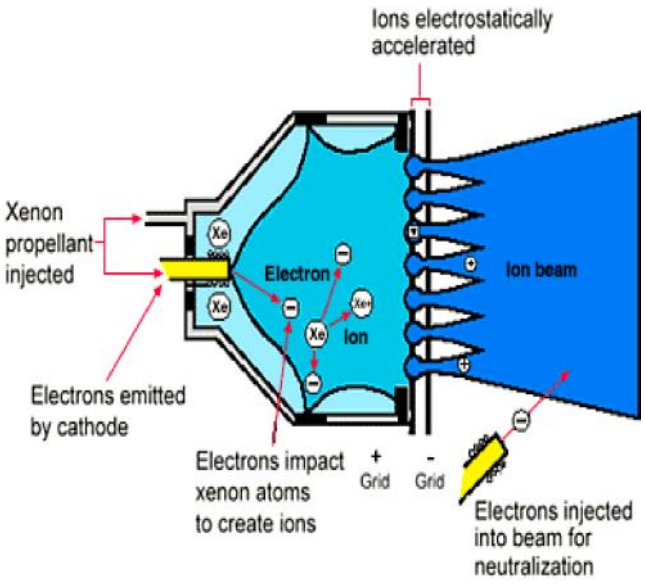
1. Boil off rate
2. Highly reactive gases
3. Leakage
4. Hydrogen embrittlement

Zero Gravity Condition

NEXT GENERATION OF ROCKET ENGINE

Generally any rocket engine burns their respective fuels to generate the thrust. 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

Figure 8: Xenon Ion Engine



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.

CONCLUSION

We can conclude that as per the Newton's third law of mechanics: Action and Reaction are equal and opposite in direction and magnitude. The thrust produced in rocket engine is outwards and that in the jet engine is inwards. Hence, the efficiency of the cryogenic rocket engine is greater than the jet engine and it is very much economical by the use of liquid hydrogen and oxygen as a fuel and oxygen.

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