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Theoretical Investigation of Liquid Propellant Rocket Engine Performance

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ABSTRACT
Liquid propellant rockets are economically more suitable for long range operations. For long range missiles liquid propellant rocket is widely used because of its suitability and performance. But when we consider high range rocket missiles, a liquid propellant rockets are not suitable, because of its size and weight is more compared to solid propellant rocket. Many liquid propellants can exist in liquid state at very low temperature itself. When more number of components present in engine panel, causing of vibration is very high and in the case of liquid propellant rocket engine it is very difficult to provide cooling of thrust chamber. There is no universal well-defined procedure or design method for making a design of liquid propellant rocket engine. Even though we followed some common concepts while making a design of liquid propellant rocket engine, there also some critical problems occur. In order to rectify such a problems we should take almost care on propellant selection and propellant ingredients. In this paper we discuss in detail about complete analysis of liquid propellant rocket engine by theoretical approach. The design and operational performance of a rocket engine is purely depends on the combustion characteristics of a propellant, its burning rate, burning surface, nozzle exit area ratio.
Keywords – liquid propellants, Propellant burning rate, Propellant burning surface, Thrust co-efficient, Nozzle exit area ratio.

I. INTRODUCTION

Liquid propellant is a combination of liquid fuel (refined petrol, liquid oxygen, hydrazine) and liquid oxidizer (red fuming nitric acid, white fuming nitric acid, hydrogen peroxide). Liquid fuel and liquid oxygen are stored separately in two different tanks and Preheater is necessary to heat the both the fuel and oxidizer. Liquid propellant rocket engines generally consists of one or more chambers, one more tanks to store the propellants, a feed mechanism to force the propellants from the tanks into the thrust chamber, a power source to furnish the energy for the feed mechanism, suitable plumbing or piping to transfer the liquids and control devices to initiate and regulate the flow. The main disadvantage of liquid propellant rocket engine is its construction is more complicated compare to solid propellant rocket. The operation of the liquid propellant rocket engine is purely depends on combustion characteristics of a propellant, its burning rate, burning surface area and nozzle exit area ratio.

The main objective of present work are:

a) To study the complete operational phenomena of liquid propellant rocket engine

b) To study the complete structural design of liquid propellant rocket engine along with its components.

c) To find the parameters, which are necessary to analyze a rocket with aid of theoretical approach.

1.1 Liquid Propellants

Liquid propellant rocket engines generally uses liquid propellants, which are the working substance of rocket engines, constitute the fluid that undergoes chemical and thermodynamic changes. Generally liquid propellant rocket engine propellant is classified into two categories. A liquid propellant which contains both the fuel and oxidizer in a single chemical is known as "Monopropellant". A Monopropellant contains an oxidizing agent and combustible matter in a single substance. Nitroglycerine, Nitromethane, hydrazine are few of the commonly used Monopropellants.

If the fuel and oxidizer are different from each other in its chemical nature, then the propellant is said to be "Bipropellants" A bipropellant rocket unit has two separate liquid propellants, an oxidizer and a fuel. They are stored separately and are not mixed outside the combustion chamber. Bipropellants have been widely used in liquid propellant rocket system.

1.2 Structural Design

The structural analysis begins when all loads can be identified and quantified. The kind of loads and timing of these loads during a life of a liquid propellant rocket engine have to be analyzed for each application and every rocket. Although ignition and accelerations usually cause high stress and strains. The maximum stress and strains can be accepted by the propellant under various conditions.

1.3 Propellant Feed Mechanism

Liquid fuel and liquid oxidizer need to be supplied to the combustion chamber at specified flow rates from the storage tanks. For this, either pumps are used or the liquid fuel and oxidizer in the tanks are pressurized by a high pressure gas source and forced into the combustion chamber. Two types of propellant feed system widely used in the liquid propellant rocket engine. Gas pressure feed system and Turbo pump feed system. In case of gas pressure feed system, Gas at ambient temperature, contained in a gas bottle at high pressure, is supplied to the fuel and oxidizer tanks through a pressure regulator to expel propellants from the tanks. In case of turbo pump feed system, Liquid hydrogen peroxide from the tank is decomposed by a catalyst such as calcium or sodium permanganate. Due to this steam and oxygen are generated. This steam is used to drive the turbine.

1.4 Combustion

Combustion of a liquid propellant (fuel and oxidizer mixture) in the combustion chamber requires the following basic processes. Injection, Atomization, Mixing, Vaporization, Ignition, Chemical reaction between fuel and oxidizer. The propellants are injected into the combustion chamber through fine orifices for proper atomization. Various methods are followed to atomize and mix the fuel and oxidizer. The combustion starts with the arrival of one of the propellants. In order to obtain a low value of the oxidizer fuel ratio, the fuel jet is allowed to enter the combustion chamber first. The combustion pressure and temperature depends on the flow rate of the propellants, the combustion rate and the gas flow rate through the exhaust nozzle.
The propellant flow rate through the injector depends on the pressure drop across, when flow rate increases with the pressure drop.

1.5 Nozzle

The supersonic nozzle provides for the expansion and acceleration of the hot gases and has to withstand the severe environment of high heat transfer and erosion. The following type of nozzles is widely used in liquid propellant rocket engine.
a) Fixed nozzles: fixed nozzles are generally not submerged and do not provide thrust vector control.
b) movable nozzles: movable nozzles can provide pitch and yaw control and two are needed for roll control. Movable nozzles are typically submerged and use a flexible sealed joint or bearing with two actuators.
c) submerged nozzles: A significant portion of the nozzle structure is submerged within the combustion chamber or case.
d) extendible nozzle: the extended nozzle improves specific impulse by doubling or tripling the initial expansion ratio, thereby significantly increasing the nozzle thrust coefficient.

1.6 Cooling Methods

The flow of high temperature gases around 3000K or higher in the thrust chamber. Most of the structural materials either melt or do not retain their strength at these high temperature. The walls of the thrust chamber are cooled, by using any one of the following methods. Film cooling, barrier cooling, Radiation cooling, Regenerative cooling, Ablation cooling, Transpiration cooling.

II. INDENTATIONS AND EQUATIONS

The following formulas were used to find out the parameters, which are necessary to investigate the entire process of the Liquid propellant rocket engine.
The mixture ratio r is defined as the ratio of the oxidizer mass flow rate m_o and the fuel mass flow rate m_f or

$r = m_o / m_f$ (1)

The thrust produced is given by

$F = m_p * Cj + (P_e – P_a) A_e$ (2)

If q is the heat supplied in the form of chemical energy per unit mass of propellant, we get

$Q = Cp(T02 - T01)$ (3)

Specific impulse of a rocket engine is given by

$I_{sp} = C_j / g$ (4)

Specific Propellant Consumption is given by

$SPC = WP / F$ (5)

Weight floe coefficient is given by

$Cw = Wp / Po A^*$ (6)

Thrust coefficient is calculated through

$CF = F / Po A^*$ (7)

Characteristic velocity of a rocket is given by $C^* = CJ / CF$ (8)

III. FIGURES AND TABLES

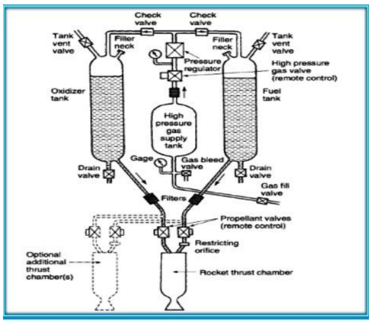

Figure 1. Liquid Propellant Rocket engine with Gas Pressure feed System.

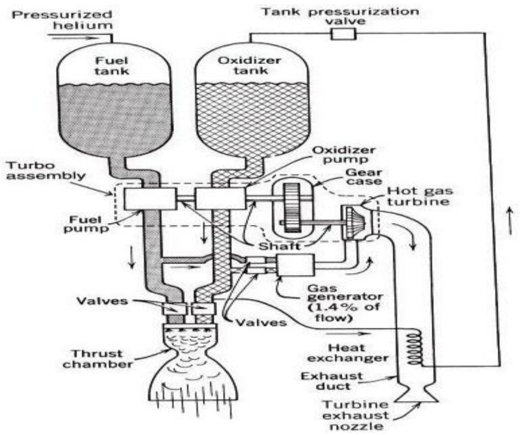

Figure 2. Liquid Propellant Rocket engine with Turbo pump feed System.

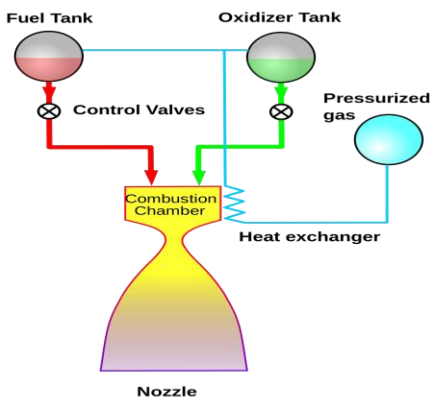

Figure 3. Schematic of Liquid Propellant Rocket Engine with Heat Exchanger.

To design a rocket nozzle for liquid propellant rocket engine the following procedure can be carried out with help of following inputs as a example

S.No	Parameter	Quantity
1	Chamber Pressure	2.068 MPa
2	Chamber Temperature	2861 K
3	Molecular mass of the Gas	21.87 Kg/Kmol
4	Specific Heat Ratio	1.229
5	Weight Flow Rate	5.6521 N/s
6	Thrust	1300 N

Table 1. Inputs for Calculation.

From the above inputs, after making a theoretical calculation by using above listed standard formulas, we have the following results.

IV. CONCLUSION

From the above theoretical work we can concluded the following aspects as a result of a present work.

1.When liquid propellant rocket engine is in motion condition, its combustion process is controllable, which means it is easy to stop the combustion by closing the fuel valve or oxidizer valve. Increase and decrease of speed regulation is possible in liquid propellant rocket engine.

2. The Specific Impulse of a liquid propellant rocket engine is very high compare to solid propellant rocket engine. It is also found that the liquid propellant rocket engine is best suitable for long range operational applications.

3. The size and weight of the liquid propellant rocket engine is more compared to solid propellant rocket engine because of it having more number of moving parts such as components which are required for propellant feed mechanism, pumps, tanks, etc.. due to more components present in the panel of liquid propellant rocket engine causing of vibration is also more. This is the main disadvantage in the case of liquid propellant rocket engine.

S.No	Parameter	Quantity
1	Exit Mach Number	2.57
2	Exit to Throat area ratio	3.557
3	Throat Pressure	1.155 MPa
4	Throat Temperature	2567 K
5	Throat Area	1.296 mm^2
6	Mass Flow Rate of the Propellant	0.576 Kg/s
7	Exit Area	4.611 mm^2
8	Exit Pressure	1.0 bar
9	Exit Velocity	2241.95 m/s
10	Throat Diameter	0.04063 m
11	Exit Diameter	0.07664 m
12	Specific Impulse	230 Secs

Table 2. Final Results.

4.From the result of a present work, the Specific Impulse of a Liquid Propellant Rocket Engine is more. The function of the nozzle is to convert the pressure energy of the gas into kinetic energy. After completing the operation of the engine high temperature and high velocity gases are expand in the nozzle section. During the nozzle operation the temperature of the nozzle also increases. In this regard nozzle need to be cooled after operation. In case of liquid propellant rocket engine we are providing some cooling methods to rectify the same problem.

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