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Theoretical Study on Characteristics of Hybrid Rocket Motor

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ABSTRACT: The paper aims at understanding the various parameters of hybrid rocket motors such as thrust control, specific impulse, burn rate, efficiency, and specific fuel consumption through the study of various research papers. Thrust vector control (TVC) is a vital part of space/aerospace manoeuvres. The specific impulse of a rocket propellant is a rough measure of how fast the propellant is ejected out of the back of the rocket. The burn rate is the pace at which a new company is running through its start-up capital ahead of it generating any positive cash flow. Efficiency results from ground tests of single-port hybrid rocket engines show measured characteristic velocity efficiency ranging from 55 to 97 percent. Specific fuel consumption (TSFC) is the fuel efficiency of an engine design with respect to thrust output.

KEYWORDS: Efficiency, Hybrid motor, Propellant, Thrust

I. INTRODUCTION

Hybrid rocket motor plays a significant role in the field of aircraft, and also they hold no advantages over solid and liquid motor systems. Hybrid rocket motors are the specific type of motors that comprises a fuel and oxidizer in different phases as well as stored differently [1]. The thrust produced is the main power source for space transportation and aerospace vehicle, and also it decides the capability of spacecraft [2]. With the help of controlling thrust, we can easily change the direction of the spacecraft. Thrust can also be varied in the case of solid and liquid rocket motors but in the case of hybrid rocket motors it has certain advantages like being cost-effective, keeping the environment clean, and safer, and many others [2]. Specific impulse is a major factor in deciding how efficient the fuel is. If the specific impulse is high, with the help of less fuel also the rocket can go perform well. Burn rate is responsible for the determination of the rate of flow which is through the nozzle, which is further used for the calculations of thrust. As a result burn rate also becomes a crucial factor. Fuel consumption is also a major topic to be taken into consideration because if the fuel consumption rate is pretty high that will lead to an increase in the budget of the project. Also, the weight of the aircraft depends upon the fuel so we want the exact with a little extra so that our requirement is fulfilled. Efficiency in technical terms means the ratio of input to output [3]. At the end of everything, efficiency is the one and only factor which matters because if a system is not that efficient then why will it even come into thought of implementing that system. All the research papers and everything are done on how to improve the efficiency so that with less usage of things we can get optimum utility.

II. LITERATURE REVIEW

Hui Tian et. al focused on the fuel regression rate characteristics of a Hybrid Rocket Motor. It was studied through three dimensions numerical simulation and a lab-scale firing test. Gaseous oxygen and polyethylene were used as propellants. Thread pitch, Groove depth, and width are the factors influencing the fuel regression rate. In conclusion, they analysed that the fuel regression rate of a hybrid rocket motor is productively increased by helical grain [4].

Yuji Saito et. al experimentally investigated an axial injection end burning hybrid rocket, which was made by high accuracy 3D printing, with the help of a laboratory-scale motor. The fuel regression characteristics of this type of hybrid rocket were studied [5].

Kirsty Veale et. al used a paraffin wax fuel hybrid rocket motor for performance testing, with specific reference to the role of additives in improving metrics such as specific impulse and density impulse. It showed that additives to liquefying propellants can improve the regression rate, but it will alter the structural properties of the fuel. Aluminum additives have been shown to increase the regression rate of hybrid fuels while providing a dense energy source while reducing the O/F ratio in the fuel through additive means. Nano-sized aluminum particles have a higher combustion efficiency, higher heat transfer, and reduced ignition delay and burn time than smaller aluminum particles. Lithium-

based particles such as LiAlH_4 are extremely reactive and have been shown to increase the regression rate of paraffin wax. Boron is a material that improves the heat release from HTPB fuel and improves combustion efficiency [6].

Sulha Lee et. al has taken an interesting and complicated physics involved research topic Low-frequency instability in hybrid rocket combustion This study will analyse the effect of enhanced small-scale vortices at the inlet due to wall blowing and the change in step height with different ERs on the generation of pressure fluctuations in the hybrid rocket combustion. An LES code was developed for the study of low Mach number flows with preconditioning and compressibility effects and the governing equations were normalized and filtered. The backward step flow is characterized by a unique frequency characteristic. The oscillatory flow characteristic $St = O(0.3)$ is difficult to observe when the shear layer is formed in sudden expansion pipe flow, but turbulent flow with wall blowing causes an additional generation and convection of vortices in the shear layer. Frequency analysis is used to understand temporal changes [7].

GuobiaoCai et.al deals with the combustion performance of the hybrid rocket motor and its advantages, including high-level safety, thrust throttling, high reliability, low cost, and less environmental pollution. Using FLUENT, a UDF is used to model the solid fuel surface by using mass, momentum, and energy sources in the control equations. In the primary flow, the secondary flow velocity is 65 m/s, the inner flow field is 1/8, and the second injection angle is 6 mm. In Case B6, the residence time of secondary injection is longer than that of other cases, so the time of staying in the post-chamber is longer, this increases the probability of chemical reactions in the post-chamber and improves the utilization of the fuel. The effect of secondary injection on the performance of hybrid rocket motors was studied by numerical simulation and experimental data. The main conclusions are that secondary injection contributes to making oxidizer well combusted with fuel gas in post-chamber and improve the utilization of propellants [8].

Kesiya George et.al researched the frequently used elastomers and presumed the characteristics of ablation and insulation. They discussed various kinds of EHSMs for SRM insulation. They concluded that EHSMs can satisfy the proliferating need for HSMs. Therefore, by changing to the new elastomeric formulation with liable Reinforcement, there will be a big change in the simulation of Rocket Motors[9].

Bo Zhao et.al experimented with hydrogen peroxide, as a throttle able catalyst in a hybrid rocket motor. Also, a few characteristics like regression rate, pressure in the chamber, thrust, and transient process, were also studied [10].

Jungeun Kimet. al used Hybrid rocket combustion shows a nonlinear characteristic that produces a low-frequency instability (LFI) where the pressure oscillation that occurs in response to external disturbances in the combustion boundary layer is amplified and caused by the thermal delay and pressure oscillation of the solid fuel. In recent studies, swirl injection has been found to stabilize combustion and reduce the pressure fluctuations of the 500 Hz band. However, swirl injection is still unclear. Here, the modulus or gain of a transfer function is the gain of a Fourier transform and the phase angle is the phase angle. The swirl injection in the main chamber can significantly affect the flame shape and turbulence structure in the post chamber, and the POD technique is a suitable tool to analyse the change of flow structure by the swirl injection with increasing swirl intensity. The swirl injection of fuel seems to alter the physical processes responsible for the initiation of LFI, namely the phase difference between two fluctuations of p' and q' of the 500 Hz band, and the pressure oscillation frequency [11].

Enrico Paccagnella et.al designed, built, and tested a small-scale hybrid rocket that can burn Hydrogen Peroxide and paraffin wax for a long time to scrutinize the capability of paraffin wax for missions as a Hybrid Fuel. To investigate the behaviour of Nozzle Assembly, the experimental results showed that the using of paraffin wax for an extended time is possible [12].

Hui Tian (et.al,2019) represents a multi-segmented grain, which is a combination of several thin grains with one or two ports, with the combustion characteristics in a hybrid rocket through 3D numerical simulations. The factors studied are the effect of rotation, fuel grain segment number, port number, mid chamber length on the flow field, and combustion performances [13].

Zezhong Wang et. al have experimentally investigated a novel fuel grain, which is paraffin-based fuel inserted in an acrylonitrile-butadiene-styrene and gives it a nested helical structure. To study the combustion performance, combustion efficiency, regression rate, pressure oscillations, and parameters of this type of grain including ignition characteristics [14].

Mengu Dinesh et. al examines the effect of single protrusion and multi production on the performance of hybrid rockets with the length/initial port diameter ratio of 12.5. The laboratory-scale hybrid rocket motor used in the present study is made of high-density graphite, with a shower head injector and motor casing. The reason for the increase in the regression rate of a double-protrusion case can be analysed by observing the burnt fuel grains. The optimal distance between protrusions is 56.4 mm, which is approximately 2.7 times the length of the upstream recirculation zone. Experiments are conducted to understand the effect of single protrusion on the combustion efficiency in a hybrid rocket motor. The combustion efficiency is enhanced in the presence of protrusion compared with the WOP case and it is increased as the protrusion moves toward the nozzle end [15].

GuobiaCai et.al used a numerical method the authors investigated the effect of head-end swirl injection under high geometric swirl numbers. They also used the three-dimensional structured mesh technology the average fuel rate reached 4.3 times the intensity of the rotational flow is influenced by the oxidizer mass fuel. Oxidizer mass fuel is proportional to fuel regression rate and inversely proportional to combustion efficiency decreases. The geometric swirl has a great impact on Hybrid Motor [16].

Zhu Haoet. al has investigated both numerically and experimentally, a Hybrid rocket motor(HRM) with an aerospike nozzle. Characteristics like velocity, combustion efficiency, thrust coefficient, and a specific impulse of the HRM with an aerospike nozzle were studied in comparison to HRM with a de Laval nozzle at different oxidizer mass flow rates [17].

Tor Viscor et.al states there has been an elevating trend of building new rocket systems with Hybrid rocket technology. He also believes this is only because of its non-explosive nature. Moreover, To explain the problem of Transient start-ups he defined some of the important terms. At last, concluded that the burnt time equivalent is a useful tool to reduce the errors and will be the major part of the CAMUI simulator and added there is a chance of using this in the future [18].

Adam Okninski et.al tries to explain the long history of the development of hybrid rocket technology, which has led to a very limited number of operating systems and low Technology Readiness Levels. Efficiencies exceeding 90%, altitudes over 23 km, a velocity equivalent to Mach 2.05, and more than 100 km of altitude were demonstrated during full-scale motor firings. Numerous tests allowed technology optimization. In the Mk2019+ test-stand firing, the ILR-33 AMBER rocket motor has demonstrated burn duration of over 40 seconds. The Lukasiewicz Research Network - Institute of Aviation in Warsaw has demonstrated the use of 98% hydrogen tetrafluoropropyl (HTP) as an oxidizer for hybrid rocket motors, and several patents have been obtained in the field of 98% HTP, hybrid rocket motor chamber technology and particular design features used in the AMBER design[19].

CagriOztan et.al have collected and compared research studies regarding hybrid rocket and their components in context with additive manufacturing. The parameters he has described are the types of materials used, the rationale, different methods, and the comparison of performance [20].

Kangkang Guo et.al showed that the mixture of O₂ and Methane is a suitable propellant for most rocket engines. He further added it is due to its low cost and practicality as if we compare it with Hydrogen. In this paper, He experimentally identified the instability of transverse combustion. Further, He verified the numerical model of the experimental results. Through this experiment, he proved that combustion instability takes place due to the in-phase pressure and release rate of heat [21].

Ankit et.al paper discussed a theoretical and conceptual design for compact size 2 stage sounding rocket by focusing on structural optimizations at various levels. The aim of the paper is to develop a two-stage sounding rocket with overall length constrained to 1 meter [25]. The aim of paper is to design a two stage sounding rocket and its nozzles using fusion 360 and analysis of different properties using simulation on ANSYS software. The rocket is designed to reach maximum apogee to perform scientific experiments and can be recovered safely after use [26]. Ankit et.al described about different classification of propellants used for launch vehicles. The cryogenic propellants taken for comparison are liquid hydrogen, liquefied methane and for semi cryogenic fuels considered are RP-1 (kerosene) and UDMH with liquid oxygen as the oxidizer. The scope of this work addresses the comparison among the propellants, on their chemical properties, overall efficiency and fatigue life which is a major criterion for launch vehicles [27]. Ankit et.al describes about a sounding rocket which is developed to perform certain scientific experiments in low earth orbit. The propulsion characteristics and calculations related to nozzles for both the booster stage and the sustainer stage of two-stage sounding rocket have been discussed and calculated using isentropic relations [28].

III.CHARACTERISTICS OF HYBRID MOTOR

3.1.THRUST CONTROL

When a liquid oxidizer reacts with a solid fuel inside the combustion chamber leads to the production of thrust in the Hybrid Rocket Motor. Thrust is the force that helps the rocket, move through the air and space [22]. The rocket's propulsion system will generate the thrust by applying Newton's Third Law. Accelerating the working fluid produces the thrust. The equation of thrust is given by-

$$F = \dot{m}v_e + (p_e - p_o)A_e \text{----- [1]}$$

\dot{m} = mass/time

A_e = Exit Area

p_e = pressure (exit)

p_o = pressure (inlet)

3.2.SPECIFIC IMPULSE

Specific impulse (usually abbreviated Isp) is a measure of how efficiently a reaction mass engine (a rocket using propellant or a jet engine using fuel) creates thrust. For engines whose reaction mass is only the fuel they carry, specific impulse is exactly proportional to the effective exhaust gas velocity [23,24].

A propulsion system with a higher specific impulse uses the mass of the propellant more efficiently. In the case of a rocket, this means less propellant is needed for a given delta-v so that the vehicle attached to the engine can more efficiently gain altitude and velocity.

For engines whose reaction mass is just the fuel they carry, specific impulse is precisely proportional to the effective exhaust gas speed. Within the case of a rocket, this implies less propellant required for a given delta-v in order that the vehicle hooked up to the engine will a lot of efficiency gain altitude and speed.

A system with the next specific impulse uses the mass of the propellant a lot with efficiency. The candidate style used a grain that gave enough thrust at a reasonably low chamber pressure, was physically sturdy on surviving landing, and would be straightforward to form. Isp result may be 10-12 seconds higher at the beginning of the burn because of AN initial O/F quantitative relation nearer to the optimum. The chart shows each ideal performance, and also the calculable performance in an exceedingly real-world engine. For the HTPB/decaborane fuel, the mixture quantitative relation was five-hundredths by mass.

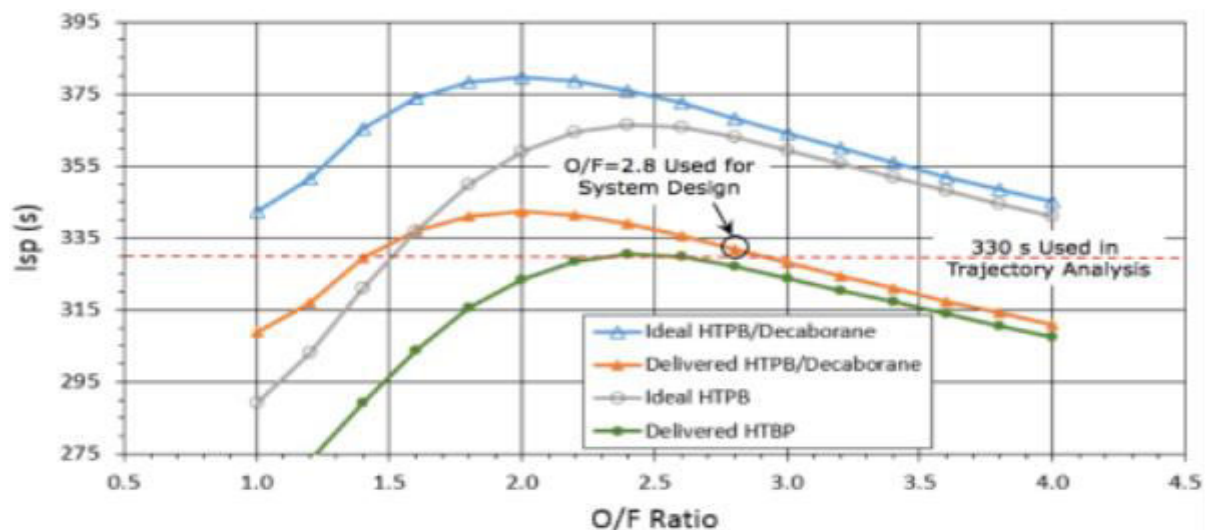


Fig 1. O/F Ratio vs Isp for different composition

3.3.BURN RATE

In the case of a solid and liquid rocket motor, the fuel and the oxidizer are in a single compartment so the burn rate is defined, but in the case of a hybrid rocket motor, the fuel, and the oxidizer are stored separately so it is more appropriate to call it as regression rate. Regression rate means the rate at which the fuel surface moves forward for the action of burn.

In the case of an axial injection end-burning hybrid rocket, the regression rate depends on chamber pressure and oxidizer port velocity.

$$V_f = (C_1/V_o + C_2)P_c \text{ ----- [2]}$$

Where c_1 and c_2 are constants,

V_f is the regression rate

V_o is the oxidizer port velocity and

P_c is the chamber pressure

3.4.EFFICIENCY

A hybrid rocket engine is a combination of solid fuel and liquid oxidizing agents or the other way around. The most advantage over solid systems is meeting the wants of missions with variable thrust, serial firing, and storage of non-toxic propellants. within the Nineteen Fifties, it had been incontestable by G. Moore and K. Berman normally Electric's laboratory the utilization of liquid oxidizing agent in hybrid engines victimization oxide containing ninetyeth as chemical agent and polythene as fuel. In 1960, investments in analysis into hybrid propulsion systems began within us. Between 1980 and 1990 AMROC (American Rocket Company) developed the biggest hybrid rockets ever. The propellant combine utilized in the developed engine was LOX and HTPB (hydroxylated polybutadiene), which generated a thrust of roughly 312kN within seventy seconds of firing. In 2001, in a joint effort between an independent agency and researchers at Stanford, a hybrid engine check facility was designed. The results showed that there was uniform grain burning and cracks within the internal walls that failed to impact the burning rate, whereas the oxidizing agent flow may be controlled by the combustion chamber valve.

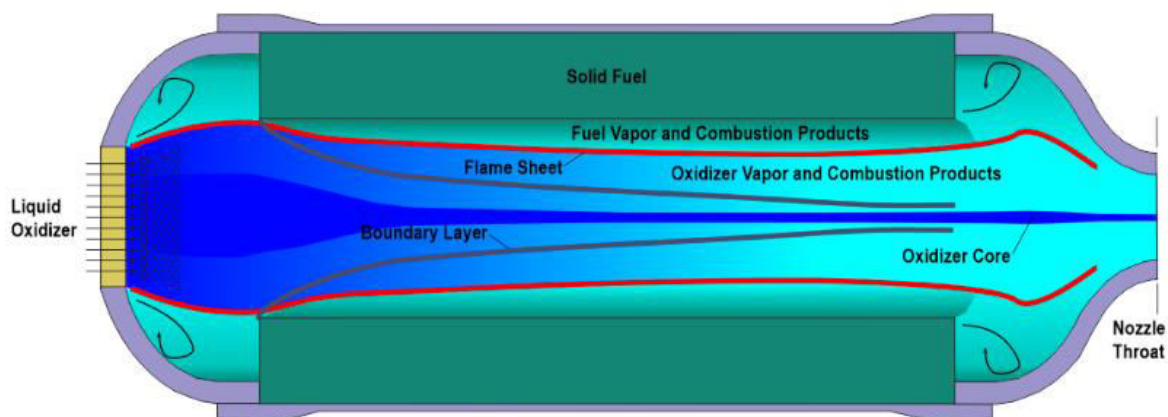


Fig.2 Topological consumption of time-averaged combustion within a single port hybrid rocket engine

3.5. SPECIFIC FUEL CONSUMPTION

In hybrid rocket engine, the rate at which the surface of the fuel decreases over the burn course is known as Fuel Regression Rate. Fuel regression rate has a great effect on the chamber length and diameter of the combustion. In addition to that, it also has an impact on motor performance. Considering the energy and safety, Hydroxyl-Terminated Polybutadiene is presently utilized as a fuel in Hybrid Rocket Motors.

IV. CONCLUSION

On account of the safety, solidity, economical cost, and elevating performance Hybrid rocket motor have a great inherent for applications of aeronautics and aerospace. The study shows that the specific impulse rate of individual liquids is higher than the specific impulse of hybrid rocket motors. Compared to solid rocket motors, Hybrid rocket motors have a high specific impulse. Hydroxyl Terminated Polybutadiene is been used as fuel in hybrid rocket motors. Thrust is generated by Newton's Third Law. This paper completely studied the characteristics of the hybrid rocket motors.

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