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Chemical Rocket Motors for Space Launch Applications: Parametric Approach

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Abstract. Hybridrocket motors are widely used in heavy launch vehicles with maximum payload capacity. The main reason for the study in this field is that the hybrid rocket motor is very easy to handle and has a simple design. In this paper, we have studied the parameters involved in designing and optimizing the hybrid rockets which provides in achieving maximum performance value. The several parameters considered for parameters involve are- burn rate, specific fuel consumption, specific impulse, efficiency. The design constraints will be responsible in achieving a high thrust level through the nozzle. The study also highlights the propellants being used in hybrid rocket motor. The collaborative research will aid in briefing the design and the working of the hybrid motors that is frequently being utilized in the industry.

1. Introduction

Chemical Rockets are the rockets in which the energy required to accelerate the propellant comes from the propellant itself, specifically from a fuel-oxidizer combination. The fuel-oxidizer combination or stored chemical propellants can be in the form of liquid, solid, or a mixture of both i.e. hybrid. In the chemical rocket due to chemical reactions between fuel and oxidizer large amount of heat is liberated which converts the propellant into hot gaseous products, when these hot gases are allowed to expand through the nozzle thrust is produced which is used to propel the rocket. The advantage of Chemical Propulsion is that they produce a large amount of thrust in a small amount of time. Liquid rocket engines continue to be the predominant chemical rocket propulsion system, from engines for spacecraft to first-stage engines for rockets. In a liquid rocket, the propellant is in a liquid state. Fuel and oxidizer are stored in separate containers outside the combustion chamber and they are injected into the chamber where the combustion takes place. The combustion produces a high amount of exhaust gases at a high temperature and high pressure. The hot gases are allowed to expand through the nozzle to produce thrust.Theoretical study has also been presented which highlights the propellants being used in the solid rocket motor. The performance parameters are also being described along with the material selection as described by Ankit et.al [8]. Ankit et.al presented a study on nozzle flow partition that is carried out by simulation of rocket nozzle designed Fusion 360and ANSYS to inspect the laminar as well as turbulent regime for deviating section of nozzle [1]. Ankit et.al reviewed about pintle injector used in rocket nozzle along with motor combination for generating higher amount of thrust. It show the influence of spray angles and characteristics such as flow as well as combustion on spray images, droplet size, momentum ratio, opening distance and SMD distributions which affect the injector geometry [2]. 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 [3].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 [4]. Ankit et.al presented a work caused by lack of data on aerodynamics for profile of elliptical nose cone and especially improved aerodynamic qualities that can be used in designing aircrafts. Flow phenomena observed in numerical simulations for different AOA for elliptical nosecone profile are highlighted, critical design aspects and performance characteristics of selected nose cone are presented [5]. Kabhilesh et.al reviewed about the materials like ceramics, hydrogels, smart metal alloys. This paper also incorporates the survey of smart materials and multi-materials along with its applications in field of space technology, biotechnology etc. depending upon the level of compatibility [10].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 [6]. Ankit et.al reviewed on magnetic pulse welding (MPW), hybrid laser arc welding (HLAW), ultrasonic resistance spot welding (URSW) of Al and its alloys with other metals. There processes are faster thanother conventional processes, are useful in mass production. Micro hardness, microstructure, porosity, tensile and shear strength, fracture and failure of the joints welded using these processes were studied and compared for major aerospace applications. The welded joints obtained showed more strength than base metal. The hybrid joints formed by HLAW & URSW are more efficient than normal processes' joint strength is 300% stronger than RSW [12].Aerodynamic thrust variation and performances play a key role in estimating forces along with the injected flow and their characteristics. This review paper deals with the aerodynamics characterization, its properties at different conditions in addition with the performance analysis of the aerospike nozzle study carried by Ankit et.al [7]. Eldho Jose et.al reviewed about carbon-based nanomaterials such as nanodiamonds, metal-based nanoparticles such like gold, silver, and aluminium nanoparticles, and electro spun nanofibers. The characteristics and uses of these chosen materials were described along the review. In addition, some of the most notable characteristics or qualities of each material are addressed, as well as their purposes. This collaborative research will aid in a briefing on the key characteristics of certain frequently utilized nanoparticles as well as their application areas [11]. Ankit et.al discusses about composition of chemical substances that affects the launch vehicle in ground station as well as atmospheric conditions is been presented. During the rocket-launching the large amount of inhalation of an exhaust gas released and it majorly affects the surface of the launch pad as well as the atmosphere [9]. 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 [14].This review paper sums up major properties for the selection of material incorporates its tensile properties and its effects, fracture mechanism, most importantly fatigue life cycle, grainsize, and its morphology, etc. The study over different grades of Al-Li alloy is summarized along with its aerospace applications mentioned by Ankit et.al [13].

2. Specific Impulse

In a demonstrator of a detonation rocket engine (DRE) using the natural gas-oxygen propellant system, a high (270s) specific impulse sea level at a low (32atm) mean combustor pressure was experimentally obtained for the first time.In a demonstrator of a DRE using the methane–oxygen propellant system, the thrust was experimentally measured at low (to 3 atm) pressures in the annular combustor. The maximum measured specific impulse at sea level was 107 s. These experimental results were developed further owing to an increase in the mean combustor pressure to 9–10 atm and a change in the DRE design, the maximum measured specific impulse at sea level using the natural gas–oxygen propellant system reached 160 s [15]. Various DRE designs were preliminarily studied by multidimensional numerical calculations of the operation process [16]. The problem facing propellant formulators is the difficulty encountered in the experimental evaluation of the specific impulse that requires hundreds of kilograms of potentially dangerous and explosives energetic materials. Consequently, researchers rely heavily on thermochemical codes such as NASA CEA or TERRA code to accurately compute propellant performance at a determined pressure ratio. Similarly, to thermochemical codes, relationships derived from empirical data present at viable alternative to compute the performance of explosives and propellants. In the recent studies, condensed explosive detonation velocity, pressure, temperature, and other performance parameters [17] as well as specific impulse of monopropellants can be precisely calculated using only few experimental data and no more than a hand-held calculator [18].

3. Burn rate

In recent years research in hybrid rockets is gaining momentum owing to experimental and numerical advances, and to an increasing number of test flights [19]. Hybrid rockets, which are propulsion devices burning a solid fuel and a gaseous or liquid oxidizer, are considered a promising alternative to liquid or solid propulsion for applications, including sounding rockets, space engines, auxiliary power units, and boosters. The burning rate modulation is a critical but challenging technology for solid propellants design. Great efforts have been made to synthesize and utilize catalysts to modify the pressure exponent (n), but poor catalytic efficiency and lower energy level of conventional catalysts limit their further applications. A reduced burning rate dependence on pressure has been achieved by interfacial control, where Al particles were coated by RDX tightly at micro-level and hence Al can be ignited at a position closer to the burning surface, increasing the heat flux from the gas-phase region to the unburnt propellant at low pressure [20].

4. Specific fuel consumption

Hybrid rockets are one of the four main chemical rocket configurations conceived during the birth of rocketry, which are: the solid, liquid, hybrid bio propellant rocket configurations and the liquid monopropellant rocket configurations. In hybrid rockets, it is necessary to predict the fuel mass consumption rate which results from boundary layer combustion, as well as the change in the chamber pressure, and nozzle expansion ratio due to nozzle erosion [21]. Hybrid rockets are uniquely suitable for the next generation of dedicated small-payload launch vehicles because they avoid the use of hazardous materials in all aspects of production and launch. With the emergence of innovative hybrid rocket motors, there is a high probability that the topic of nozzle erosion will take on an increasingly important role as well. This is because the most common hybrid rocket propellant combinations lead to higher concentrations of oxidizing agents in the combustion gas that passes through the nozzle throat [22]. The fuel mass consumption history and the nozzle throat erosion history determined by the nozzle throat reconstruction technique are repeatable, and have acceptably low experimental uncertainty. An analysis of the fuel mass consumption histories determined by the nozzle throat reconstruction technique demonstrates that an increase in surface regression rate is achieved as a fuel grain becomes more (cascaded multistage impinging-jet) CAMUI-like. As hybrid rockets continue to increase in scale and performance, and capture the attention of the commercial sector as a safe and low-cost propulsion system, performance related issues such as nozzle erosion and fuel mass consumption will become even more relevant.

5. Efficiency

High combustion efficiency is a critical attribute of a successful rocket engine. The combustion efficiency results from ground tests of single port hybrid rocket engines show measured characteristic velocity efficiency ranging from 55 to 97 percent. The rocket designer is compelled to balance numerous factors including performance, safety and cost when making design choices and of the consideration, combustion efficiency is near the top of the list. There is a general knock against hybrids in the propulsion community is that their combustion efficiency is low. But there are some examples of hybrid rocket engines that have achieved combustion efficiency, one of them is most recent ground tests of MON-25/Paraffin single – port hybrid configuration under consideration for a mars ascent vehicle (MAV) mission achieved a burn average characteristic exhaust velocity efficiency [23]. The efficiency starts out high at the beginning of a burn and decreases at the fuel port opens up over the course of the burn. Also, the turbulence within the combustion chamber and propellant chemical kinetics are important to achieving high efficiency. For the advance hybrid rocket technology development, a new test bench has been designed and built to conduct fundamental research on regression rate and characteristic velocity efficiency. This will give greater insight into the fundamental aerodynamic/ thermochemical coupling driving heat transfer phenomena and improve understanding of reactive mixing in the combustion chamber [24].

6. Conclusion

In this paper we have discussed, the performance parameters for rocket motors such as specific impulse, burn rate, efficiency and specific fuel consumption. Detailed discussion has been made on the experimental evaluation of specific impulse which requires large amount of energy materials. Fuel required burn rate which modulation is critical as well as challenging. The analysis on fuel mass consumption has been also mentioned by using nozzle throat reconstruction technique. As hybrid rockets performance, safety, low-cost, etc. these advantages become fuel mass consumption more relevant and efficient. Finally, studied the efficiency which is critical attribute of a successful rocket engine, but some could achieve it by efficiency starts throwing out the gas faster, which force per unit mass of propellant is high.

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