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GREEN PROPULSION: AN EMERGING TECHNOLOGY IN SPACE INDUSTRY

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Abstract: *To overcome Earth's gravity and to elevate even a lighter payload to mass a large amount of Propellants is required. The hazardous nature of the propellants used for the spacecraft launches and the negative influence of its chemicals to be considered. Space investigation and exploration have a major role in the new trends of development and technological progress. The research in green propulsion also have significant role. The space products industries and rocket propulsion is now showing an increased interest in non-hazardous or green mono-propellants.*

Key Words: *Green Propulsion, Mono propellant, Hydrazine.*

1. INTRODUCTION:

It is evident from the analysis that the Green Propulsion research is steadily increasing which is a proof of a positive responsible change to protect the environment, indicating the collaborative nature of the research activities. Green Propellants are basically chemicals, which are competitively safe for the environment being a promising candidates to replace hazardous storable substances like hydrazine and its derivative, nitrogen tetroxide etc. Hydrazine and oxides of nitrogen has a great potential as rocket propulsion and have been the fundamental propellants for chemical space propulsion since 1960s. however they are considered as undesirable propellants due to its harmful effects on the environment and even-though no permanent effects are found when properly treated they are toxic when inhaled, ingested or by skin absorption. So as an alternative solution for replacing hydrazine and its derivative, a new term was introduced to the space propulsion called "Green Propulsion". Improved safety and handling performance of green mono-propellants is its major fundamental benefits. Since all propellants effect the environment in some way due to the harmful gases including carbon dioxide, nitrogen oxide which are produced during the exhaust. Green propellants are said to minimize this impact. In addition, most green propellants provide increased performance compared with convectional propellants, generally expressed in terms of higher density specific impulse. Density specific impulse commonly consist of the key performance, which defines the metric for tactical applications related to upgrading programs aimed at enhancing system's performance while remaining within an existing vehicle physical envelope to preserve supporting infrastructure and thereby avoid additional system cost. The main expectations of green propellants are low toxicity that reduce operation risks and safety precaution during handling and storage reducing both ground and space atmospheric toxicity and maintenance complexity.

2. IMPACTS OF THE ROCKET PROPELLANTS:

Hydrocarbon based solid fuels used in combination with solid oxidiser ammonium perchlorate can cause serious health hazards for humans due to the leaching of perchlorate from discarded motors and from manufacturing process while discarded to ground water.HYDRAZINE ALTERNATIVE Storage of hydrazine is complicated due to its toxicity and is costly to handle. Hydrazine is normally unsteady and unvented hydrazine tanks are revealed to blowout in space, presenting a debris risk at the end of mission life. A satellite thruster based on an aqueous ADN solution was manufactured by a swedish company ECAPS that can yield higher specific Impulse than monopropellent hydrazine. Although Ammonium Dinitramide and Hydrazinium Nitroformate have low oxygen balance and less heat of reactants formation they have superior specific impulse and the exhausting gas of their burning has no hydrochloric acid. Since it does not contain chlorine, the environment is not burned with hydrochloric gas produced in the burn of the propellant. Thus ADN is a potential alternative for both perchlorate and hyrdazine monopropellants. HAN can be possibly used in aqueous solution as a substitution to hydrazine. Nitrous oxide are usually nontoxic, non-corrosive and stable under normal operating conditions. It is easily liquefied under pressure hence stored as a liquid. The reaction products of nitrous oxide are nitrogen and oxide are also non-hazardous. Mixture of dinitrogen monoxide (N20) and ethene (C2H4) is a premixed propellant called HyN0x performs high performance and low toxicity. But the two major drawback are that there is a danger of flashback flame across the injection system and high combustion temperature. To avoid the first demerit suitable flashback arresters are used. Hydrogen peroxide go through catalytic decomposition, releasing water vapour, oxygen and heat. At higher temperature, additive combust in the presence of oxygen generate even higher temperature. Dinitrogen tetroxide can be deadly after a few minutes of exposure during leakage or poor handling The exhaust left behind from the missiles can result in depletion of ozone layer. At high temperature Hydrochloric acid dissociates in to H+ and Cl- radicals then react with ozone layer decomposing it in to O2 and forms compounds such as ClO, ClO2, ClO3 etc. Currently used propellants for space application are mostly poisonous and carcinogenic. Handling and performance of toxic propellants constitute a significant cost factor. The safe handling and quality feature is a new innovation in propulsion system. Basically there are four areas to be focused which served the green technology development. They are listed as follows

- Lower life which consider identifying opportunity to cut back overall mission cost of current green propulsion system eg: ground handling, safety.
- Hardware development which means progressing the specific hardware required for making green propulsion trades eg: valves, seals etc.
- Predictive capability includes development of analytical tools necessary to predict and plan for system performance eg: Combustion codes, thermal models etc.
- Alternative applications involve exploring alternative options for green propulsion eg: dual mode electric propulsion.

3. REQUIREMENTS:

The selected green propulsion should satisfy a few set of requirements to replace hydrazine and its derivatives. Any propellant that does not satisfy the minimum requirements are considered unacceptable. The physical properties of the propellant must be known in detail in order to design a propulsion system. For eg: the density and viscosity of the propellant will have a major impact on the feed system, whereas the heat formation of the chemical composition will determine the specific impulse and the combustion temperature, this influences the design of the combustion chamber, cooling cycle and the nozzle. Toxic and explosive properties of the propellant influences how it is handles and how the thruster testing is performed.

4. PROMISING GREEN PROPELLANTS:

Promising green combinations are LOX with kerosene, propane and methane, in general, the green development points out for low thrust space engines increasing specific impulse, storability performance, decreasing volumes, reducing life cycle costs and looking for common storage and synergies between main thrusters and the altitude control ones. Electric Propulsion provides another potential green alternative. Electric thruster have the advantage of high specific impulse when compared to chemical thruster and they use much less propellant than a hydrazine vehicle to achieve the same maneuver. But a demerit of electric power source is that it usually supply only low thrust hence take longer time to deliver a satellite to orbit. Many satellite have appropriate power generation on-board for other applications, so electrical thrusters need not add mass but the longer delivery time makes it unsuitable. The xenon released from electric propulsion is generally not an environment hazard, however the iconic plume can affect the space environment.

Several potential bi-propellant formulation that use liquid oxygen (LOX) are being produced as potential hydrazine replacements. In general, these propellants are much less toxic than hydrazine derivatives, however the cryogenic nature of liquid oxygen makes it hazardous to produce and difficult to store for long periods. LOX based formulations are less approved for spacecraft propulsion because they require heavily built tanks and feed lines and need large amount of energy for refrigeration. Still, LOX/ hydrocarbon fuels render higher specific impulse than hydrazine monopropellent. When compared to kerosene, methane can be potentially used as a fuel rich gas generator in the absence of soot formation, it also feature a high cooling efficiency. Methane is injected in a gaseous state, thus lowering the uncertainty of combustion instabilities. Hydrogen peroxide can also be utilized as a part of bi-propellant. For the methane based system, results indicated that the combustion efficiency is strongly influenced and improved by introduction of a swirled flow in the injector inner channel. According to the numerical simulations of the combustion, Pintle injector type and for coaxial with inner swirl has indicated the best results. Cold gas thrusters is used on satellite for both maneuvering and for altitude control and are suitable for applications that require very low total impulse. They also offer a wide range of chemical propellants because the gas need not be combustible to provide thrust. Cold gas thrusters is an attractive option in nano-satellite and low thrust propulsion engines due to its simplicity. Ammonium dinitrate ADN is evaluated as a green alternative to ammonium perchlorate. It is considered not only as carcinogenic but also as non-allergenic. Even though it cause irritation when swallowed, it does not cause irritation when in contact with eye or skin. Studies also shows that ammonium dinitrate is mutagenic. Moreover it has no apparent vapour pressure which enables low occupational exposure Aluminum Ice or in short ALICE is a green propellant developed as an alternative for ammonium perchlorate, having theoretical specific impulse hydrogen and aluminum are the main exhaust components of ALICE, which are generally considered as environmental friendly. Moreover, stratospheric alumina has the potential to minimise ozone concentration. On the other hand convectional perchlorate based solids produce exhaust which are harmful contaminants. A simple and robust subsystem called catalytic ignition was investigated for that various catalyst have been prepared including ceramic pellets, ceramic monolithics, metallic foams etc. NOFBX is a latest mono- propellant technology that extends vital satisfaction than current storable liquid propulsion technology for spacecraft reaction control and maneuvering systems. Principal characteristics are specific impulse, nontoxic elements and environmental friendly discharge. The low cost of the material combined with a fabrication process results in a highly repeatable extremely low recurring engine cost. The extensive characteristics of NOFBX technology leads to possible significance in future and enable missions that are currently insufficient. Green Propulsion Infusion Mission (GPIM) has been selected as an advanced form of thermal insulation called IMLI that is Integrated Multi-Layer Insulation that could become standard on future satellites and cryogenic subsystems. Validating the new insulation help NASA build a long human space mission technology in space.

5. FUTURE SCOPE:

Solar sail: Even though the concept of solar sail was proposed 50 years ago, it is not practical for Earth orbits, where atmospheric drag would overcome the force generated. Still, solar sail that rotate with the craft is suitable for other orbital use. Future development can possibly come with the use of sails that can act as both solar panel and as propulsion device. Storable propellants can be classified in to three groups; Mono-propellant: such chemicals fuels does not require a special oxidiser and it requires only one fuel line instead of a fuel and an oxidiser line. Pre mixed propellant. Bi-propellant: Such rockets uses a seperate liquid fuel and oxidiser propellants. Combination of bi propellant with existing green propellant could offer even greater performance gains. Green propulsion technology could enable similar mission profiles of traditional hypergolic bi propellant system.

4. MATERIALS AND MANUFACTURING TECHNIQUES:

Green propulsion provides enhancing features to space chemical propulsion. A clear understanding of materials and compatibility will permit lower cost system and evaluation of internal structure limitations of the existing design. It often utilizes special materials including refractory material Iridium (Ir) or rhenium (Re) to survive the higher temperature and oxidative corrosive environment. The hardware designs utilizing these materials typically have longer and expensive fabrication methods. Improved manufacturing methods are required to minimise the expense with these materials, because comparatively the cost required is more than that of to hydrazine thruster systems. Thermal properties of these materials particularly at elevated temperature for type of thrusters is lacking. Material compatibility especially for soft goods is not clearly known. These systems require proper heat rejection and management due to the high temperature experienced. To gain knowledge about impacts to spacecraft experienced by green propellant thrusters,a thorough study about thermal models and designs need to be done.

5. ADVANTAGES OF GREEN PROPELLANTS:

Organizing: additive layer manufacturing provides means to produce parts with one machine. Thereby, allowing the manufacturing of components within hardly few days and so production efficiency can be expanded; Flexibility: this offers new opportunities during the development regarding design modifications and substitute component configuration

Trade off method:

Propellants are evaluated by the propellant trade off method to select the most promising mono-propellant and bi propellant for future purposes. In this method, the propellant are assessed based on a trade-off criteria also called as " Measure of Effectiveness" or in short MoE which are quantities used to assess how well a propellant performs beyond its requirements. The Measure of Effective includes the following criteria, Gravimetric Specific Impulse, Volumetric specific impulse, chamber temperature, freezing temperature, health risk fraction, availability, ignition characteristics, and uncertainty of meeting requirements.

Value function:

Value function is used to define the relation between the actual value of a trade-off parameter and the corresponding trade off score, which is a number between 0-10. The 3 value functions are, "the higher the better", "the smaller the better" and a three level discrete function.

In addition to score, a relative weight factor is also used which includes three criteria. They are balanced scenario, maximum performance scenario and conservative scenario

Nithromethane was identified as a compromising mono propellant but the trade-off for bi-propellant fuel shows that nitromethane is not suitable for a bi-propellant propulsion system. Due to the slow decomposition rate and the unfavorable ignition characteristics, it was concluded that the pure nitromethane is not an attractive choice. However by adding certain oxidizer rich components to nitromethane can improve its ignitability and the decomposition rate substantially hence a nitromethane based mono-propellant is a promising choice.

Hydrogen peroxide HTP class as green propellant face some issues including thermal decomposition hence heterogeneous catalyst is employed since HTP decomposes thermally at the temperature range of 470 to 540 degree Celsius. Catalyst lowers the activation energy thereby initiating HTP's decomposition at ambient temperature. Another major issues related to hydrogen peroxide is its long term storability and compatibility. Only class 1 materials such as pure aluminum and PTFE after additional surface treatment is recommended for usage of long term storage, class 1 liners covering class 2 structures materials are avoided since failure of linear can make the whole system fail Aircraft performance modelling.

The aircraft performance modeling and simulation is done using a tool HERMES, which is capable of predicting aerodynamic characteristics combined with turbomatch in order to calculate the overall performance as an integrated aircraft system. It simulates complete trajectories, mission and produce outputs and various engine parameters during the flight schedule.

A propulsion system integration module is used for optimising nacelle geometry and engine position based on plant cycle optimisation requirements.

6. OPERATIONAL COST ANALYSIS

The operational cost is calculated for five different prices and mission taxation scenarios. The first scenario in the BAU (Business as Usual) scenario reflecting the current fuel prices and no taxation on carbon dioxide emissions. The carbon taxation levels and fuel process used scenario is used to examine the progressive effects of increasing taxation and fuel process to very high levels The fuel burn and block time are used to calculate the operating cost for the overall mission. The significance of toxic free propellants theoretical investigation of suitable green propellants Once a propellant is suitable as green propellant its various characteristics that it utilizes in the spacecraft, must be taken in to account, it should have a minimum temperature limit. Under such optimisation the solubility curve of ADN indicates that the maximum quantity of AND can be dissolved in a methanol of water mixture at a temperature of 0 degree Celsius and the maximum specific impulse was found for the methanol and water mixture having 30.6% methanol.

7. ADN ARCHITECTURE:

The major technical benefit of this system is that it can operate an optimising thrust throughout the direction if the mission. Unlike bi-propellant design there is no threat of propellant or oxidiser mixing, or unbalance of mixture ratio hence it provides riskless longer missions and also allows greater payload capacity at allotted launch cost. The ECAPS high performance green propulsion technology has been proved to be an enabling technology for improved performance and also significantly reduces hazards and fuelling efforts.

8. CONCLUSION:

The two main criteria that a green propulsion must satisfy are lower cost, diminishes operational hazards and better performance than the existing propellants. Introduction of LOX/ hydrogen, LOX/ kerosene and electric propulsion were the forward steps to limit the environmental impacts from launch vehicles. Currently the space development is gaining attention to green propellant due to its reduction of cost and pollution free environment, safer working environment, good storability, wide material compatibility, low cost, increased mission applicability and better propulsion characteristics. The green fuel on orbit can accompany many advantages for future satellites including longer mission duration, additional maneuverability, increased payload space and simplifies launch processing.

REFERENCES:

1. Rupesh Aggarwal, Ishan Patel, P B Sharma, Green Propellant : A Study, International Journal Of Latest Trends In Engineering And Technology 6(1)
2. Amir S Gohardani, Johann Stanojev, Alain Demaire, Kjell Anfloc, Mathias Persson, Niklas Wingborg, Christer Nillson,Green Space Propulsion - Opportunities And Prospects, Progress in Aerospace Science(2014)
3. Pawel Surmacz, Green Rocket Propulsion Research And Development At The Institute Of Aviation: Problem And Perspectives, Journal of KNOES 23(1): 337-344, Sept 2016
4. Dov Hasan, Dan Grinstein, Alexandeer Kuznetsov, Benvensite Natan, Zohar Schlagman Avihay Habibi And Moti Elyashi Green Comparable Alliterative Of Hydrazine Based Mono-Propellant And Bi-Propellant Rocket Systems, July 16, 2018

5. Alfons Mayer, Wolter Weiling, Green propulsion research at TNO the Netherlands, Transactions of the Institute of Aviation, 4(253)2018, pp1-24
6. Final Report Summary- GRASP (Green Advanced Space Propulsion), European Commission CORDIS EU research results 18 Jan 2013
7. Gilson Da Silva, Simone Carvalho Rufino. Koshun Iha, Green Propellants: Oxidisers, J Aerospace Technology, Manag, Vol 2 no 2, pp 139-144, April-Jun 2013
8. Herbert J Kramer,(GPIM Green Propulsion Infusion Mission), "Observation Of The Earth And Its Environment: Survey Of Missions And Sensors", 4th Edition
9. V. Batonneau, R. Brahmi, B Cartoxia, K Farhat, C Kappenistein S Keav, G Kharchafi-Farhat L Pirault- Roy, M Sacuable, C Schaelemann, Green Propulsion: Catalysts for the European FPT Project GRASP, 22 Nov 2013
10. Greg Mungas, Max Vozoff, Brian Rishckof, NOFBX : A new non-toxic "green" propulsion technology with high perform and low cost, Volume IAC-12-C4.9.10 Oct 2012
11. Asathy Sathi Sa, Saravanan G, Research trends in green propulsion : A Scientometric Perspective, Emerging Trends and Issues in Scientometrics, Infometrics and Webometrics, Nov 2015
12. D P Cavender, W M Marshall, A P Maynard, 2018 Green Propulsion Technology Development Roadmap, NASA/TP-2108-2019861