iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** IV **Month of publication:** April 2023

DOI: https://doi.org/10.22214/ijraset.2023.50081

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

Review on Sustainable Development of Space Vehicles

Shreya N Wishwakarma[1], Atharva N Dingore[2]
[1]*B.E. Student, Department of Mechanical Engineering, Guru Gobind Singh College of Engineering and Research Centre, Nashik, Maharashtra, India*
[2]*M.Sc. Student, Department of Space Engineering, Universität Bremen, Bremen, Germany*

Abstract: As humanity is moving towards becoming a multi-planetary civilization, it is very important to make efficient use of resources available on our planet first and then head towards exploiting the resources of another celestial body. It is also important to cause minimum harm to the space environment around our planet as well as the planetary atmosphere. Advancement in conventional rocket fuel is one of the ways to optimize the consumption of fuel during a space launch but it cannot always be feasible. Finding cheaper alternatives like Biofuels can also be a significant point of discussion. Such fuels can be naturally obtained without much harm to the environment and they can be as effective as conventional rocket fuel. For complete sustainability, not only internal changes but also external changes should be considered. To attain space sustainability, we need to follow a technology-driven approach while considering the cost and effective management of the space missions. This paper is a review of various techniques involved in the sustainable development of space vehicles, and effects of existing techniques involved during the launch of the space vehicle.
Keywords: Rocket Fuels, Biofuels, Sustainable Space, Orbital Debris, Propellant.

I. INTRODUCTION

The idea of sustainable development was originally introduced to the world in 1987 at the United Nations in an effort to establish new perspectives on reality. The space sustainability means that all people will be able to use it in the long run for peaceful reasons and socioeconomic gain. International dialogue, cooperation, and agreements to ensure the safety, security, and peace of outer space will be necessary for this. More than 1,800 satellites are in orbit around the Earth, bringing billions of people around the world real social, scientific, tactical, and economic benefits. The rising amount of junk in orbit presents one difficulty. Debris-on-debris collisions will continue to grow the amount of debris in orbit even without additional launches, according to some experts, who estimate the population of debris would reach a point at which it becomes self-sustaining.

Accidents and deliberate destructive actions can both result in large quantities of orbital debris that represent a threat for decades or centuries. Smaller amounts of waste can be produced during routine operations. The fact that orbital debris is a global crisis illustrates the need for international cooperation to maintain the long-term sustainability of space.

Chemical substances or mixes that may burn without the use of oxygen are known as propellants. Solid, liquid, and hybrid propellants are the three categories into which propellants belong. Examples include hydrazine, liquid hydrogen and oxygen, ammonium perchlorate, kerosene, PBAN (polybutadiene acrylonitrile) rocket fuel, methanol, salts, and HTPB (hydroxyl terminated polybutadiene), and others. For a substance to be a suitable propellant, it must meet a number of criteria, including particular thrust, regression rate, specific impulse, temperature, pressure, combustion, burning, gases evolved, granular arrangement, hardness, tensile strength, weight, density impulse, kinematics, etc [3]. The burn rate of solid propellants is a vital parameter for design of solid rocket motors and can be tailored by using different constituents, extent of oxidizer loading and particle size. During rocket abort or launch pad malfunction, behaviour of aluminium particle combustion becomes complex and aluminium appears to melt, agglomerate or form a skeletal structure [2]. The advantage of LH2 as a propellant in the space sector is its high energy density, enabling it to store more energy compared to conventional fuels. It also has the potential to decarbonise space flight, but it needs to be extracted from hydrocarbons and water before use. To determine whether engine performance may be enhanced, tests should be conducted using various fuel and oxidizer mixtures. The goal of sustainable engineering is to maximize the gains and trade-offs that result from human-designed systems' influence on the economic, social, and environmental systems.

As a low-carbon substitute for fossil fuels, biofuels are being promoted as a means to lessen greenhouse gas (GHG) emissions and the associated impact of transportation on climate change.

The evidence currently available indicates that first-generation biofuels can, on average, emit fewer greenhouse gases (GHGs) than fossil fuels when there is no land-use change (LUC), but the reductions for most feedstocks are insufficient to achieve the GHG savings mandated by the EU Renewable Energy Directive (RED). However, assuming there is no LUC, second-generation biofuels generally have a larger ability to cut the emissions. With their greater GHG emissions than fossil fuels, third-generation biofuels do not currently constitute a viable alternative.

Incidents involving severe space weather could have an influence on other countries, necessitating government planning and international cooperation. In order to protect the long-term viability of space assets and even basic electrical infrastructure, better research and understanding of helio-physics, the Earth's magnetosphere, and mitigation strategies are needed.

Paper is organized as follows; Section II describes the contributions of various researchers in advancements of rocket fuel and Different techniques used for analysis. Section III presents development in Biofuels. Details about Space Sustainability are given in Section IV. Finally, Section V presents a conclusion.

II. ADVANCEMENT IN ROCKET FUEL & EXPERIMENTAL VERIFICATION

Aviation fuels have been playing an essential role in social-economic development, but the demand for fossil fuels is increasing due to urbanization and dependency on carbon-based fossil fuels. The selection of the optimal sustainable AAF is a multi-criteria decision-making (MCDM) problem, as it compares relative priorities in a finite set of alternatives. Naijie Chai, et al uses a comprehensive criteria system to evaluate sustainability performances of AAFs [13]. Interval valued triangular fuzzy numbers (IVTFNs) are used to measure sustainability performances, and a hybrid MCDM approach is developed to select the most sustainable AAF. Four AAFs are studied to illustrate the applicability of the method. The ranking of the four AAFs indicates that Algal-based fuel is the best option, followed by Soybean-based fuel, Petroleum refining, and Fischer-Tropsch synthesis based on natural gas. The sensitivity analysis shows that their ranking is sensitive to the parameters α, β and γ within the prospect value function. The comparative analysis illustrates the rationality and flexibility of the method proposed in this study.

In the area of rocket propulsion technology, propellants have been the main focus of research and development. Faris M. AL-Oqla, et al, build hierarchy decision-making model was used to better evaluate the performance of various types of fuel materials and select the most appropriate one for rocket propulsion technology [16]. It was found that the hybrid rocket type was the best regarding size and explosion sensitivity, but the worst regarding explosive sensitivity, toxicity, and operability. The liquid rocket type is the preferable one regarding performance, stability, and controlling the ignition criteria, but the best regarding explosive sensitivity. The proposed hierarchy model was successfully implemented to solve the current conflict multi-criteria problem and provide a valuable instrument for testing the consistency of assessment and alternatives, thus reducing the bias in decision making.

A. *Solid Propellant*

The combined data of the three propellants; hydrazine, AND (Ammonium dinitramide), and hydrogen peroxide are discussed by Janani Kavipriya VS, et al [22]. Due to its high density, hydrogen peroxide is a viable material for propulsion systems. The theoretical and vacuum Isps of hydrazine are higher, however 20% lower than those of hydrazine. In terms of adiabatic flame temperature, which is the temperature the propellant attains when heat is not released from the combustion reaction's products, hydrazine, ADN, and hydrogen peroxide have differing densities. When compared to hydrazine and hydrogen peroxide, ADN's value changes dramatically. Wioleta Kopacz, et al, discusses the potential use of hydrogen peroxide (HTP) as oxidizer for solid rocket propulsion in form of grains [5]. It has been known for many decades, but its application has been limited due to storability and safety issues. With the availability of new grades of HTP with higher purity and concentrations, enhanced performance, safety and storability are possible. To ensure proper analysis of the potential of using HTP in next-generation solid rocket propellants, this paper reviews existing rocket propulsion applications of HTP. Solid cryogenic propellants using hydrogen peroxide are mentioned, but focus is given to solid propellants which could ensure flexible operations. Challenges of HTP application as an oxidizer are addressed, including its reactivity. The low density of HTP is not a disadvantage, as it increases the average propellant density. The proposed propellant family has no HCl in its combustion products and offers a green solution for next-generation systems. The preliminary theoretical performance assessment shows that specific impulse of over 350 seconds is possible, making it competitive to classic storable liquid rocket propellants and narrows the performance gap between solid propellants and liquid rocket propellants using LOX with hydrocarbons. High grades of HTP are preferred to maximize performance and storability, but extensive work is needed to assess compatibility issues and thermal stability. HTP-based propellant grain and SRM scaling effects, including operation with different heat fluxes, internal flows and erosive burning phenomena, are needed to implement the novel solution in existing SRMs.

The proposed SRM technology could be used for suborbital test flights, high specific impulses, volumetric performance, non-metallized propellants, and high-performance gas generators. O.V. Romantsova, et al, discusses the possibility of producing high-concentrated hydrogen peroxide with the Russian technology of isopropyl alcohol autoxidation [10]. Analysis of fire/explosion hazards and reasons of insufficient quality is conducted for the technology. Non-standard fire and explosion characteristics are defined for the production. The main hazards of the process include potential risk of explosions, autoignition of the working mixture, forming dangerous agents, and non-standard safety ratings.

Riccardo Gelain, et al, presents a review of the principal concepts of 3D printing processes and extrusion techniques that can be suitable for paraffin grains manufacturing and the conceptual design of a prototype for a 3D printer system [1]. Paraffin-based fuels have been in the spotlight of the research related to hybrid rocket propulsion systems. However, pure paraffin has poor structural characteristics and sometimes has low combustion performance. 3D printing and the mixing of wax with energetic and/or nano-sized metallic particles can help to increase burning rates and provide mechanical strength to the fuel grains. 3D printing can also be used to manufacture complex geometries quickly and cost-effectively, allowing the realization of advanced port geometries and non-conventional swirl patterns, improving turbulence in the combustion chamber and the burning surfaces, increasing the motor combustion efficiency, regression rate, and control on shifting mixture ratio. To enable a 3D printing manufacturing process, extrusion devices such as gear pump extruders, ram extruders, screw extruders, atomization, and coaxial heat exchanger extruders are needed. The most important details are that the heat provided by the pads was not enough to keep paraffin in its semisolid state, and that the hopper was not heated before entering the barrel. An alternative design has been proposed, which is a compromise between the ram extruder and the coaxial heat exchange extruder. 3D printing manufacturing is used to manufacture hybrid rocket fuel grains featuring a special grid-like structure in order to control combustion performance. An innovative penetrative combustion mechanism, capable of affecting regression rate, was noticed during the combustion of low-packing density grains. Yash Pala, et al, aimed to increase the performance characteristics of paraffin-based fuel by using magnesium diboride (MgB2) and carbon black (CB) additives [15]. The mechanical performance results revealed that adding CB and MgB2 improved the ultimate strength and elastic modulus of the fuel, while thermal stability improved the thermal stability of the paraffin matrix. The characteristic velocity efficiency was found to be 68% to 79% at an O/F ratio of 1.6. The mechanical performance results showed that adding nano-sized CB additives improved the ultimate strength and elastic modulus, while adding micro-sized CB additives did not significantly improve. The thermal stability of the paraffin matrix was slightly improved with the addition of the CB additive, and the average regression rates increased by 32% and 52%, respectively, over unmodified paraffin wax. The oxidation furnace tests showed that the characteristic velocity efficiency of tested fuels was 68% to 79% at an O/F ratio of 1.5. The high combustion efficiency of the fuels could be attributed to the vapor phase combustion of Mg. These results are vital for accurately predicting the performance characteristics of the particular propellant combination.

The thermal decomposition of ABS was analysed by infra-red spectroscopic analysis (FTIR) and thermogravimetric analysis-differential thermal scanning (TG-DSC) was studied by Xiaodong Yu, et al [17]. The internal structure of the ABS grains was observed by high-resolution 3D micro-computed tomography (μCT). All fuel grains were burned in a hybrid 2D radial burner, allowing visualization of the combustion process and evaluation of the ballistic parameters. The results suggest that the combustion process of the ABS porous grains includes two regimes, both featuring an increased regression rate. The innovative concept of penetrative combustion is proposed, which provides a new approach to the combustion process of hybrid rocket fuels.

Aluminium particle ignition behaviour in open atmosphere rocket propellants fires is of particular interest for preventing accidents for rockets carrying high-value payloads. Nadir Yilmaz, et al, focuses on the effect of the oxide barrier which forms on the surface of aluminium that is recognized to impede combustion of aluminium in solid rocket propellants [2]. A recognized criterion is the melting of the oxide layer at 2350 K, but in other situations, there will be defects in the oxide shell which provide for aluminium ignition at lower temperatures. Paper reports experimental findings involving oxyacetylene torch, thermogravimetric analysis with differential scanning calorimeter, aluminium particle heating, electric ignition and aluminium powder heating. Also, it examines the impact of oxide layer on aluminium particle combustion. The majority opinion is that aluminium begins to combust in air once the melting point temperature of aluminium oxide is reached, but a lower temperature can yield ignition of aluminium as well. It is conjectured that flaws or weak points in the oxide shell can provide a premature breach point where the oxide barrier will fail mechanically and allow aluminium vapor to escape at temperatures lower than that required for the oxide coating to reach its melting point.

C. Glaser, et al, assesses the impact of stepped hybrid rocket solid fuel grains on the performance of the engine [18]. It found that shorter grains (118 mm) exhibit higher regression rates for Forward Facing Steps (FFS) than for Backward Facing Steps (BFS), while longer motors (500 mm) profit more from BFS than FFS.

For the Université Libre de Bruxelles (ULB) motor, the FFS increased the average regression rate 41.3% above the reference trend line, while for the HYCAT motor, the trend was reversed. The deciding difference between ULB and HYCAT concerning the employment of steps is not the different propellant couple, but the total fuel grain length. The local regression rate profiles of both cylindrical campaigns suggest that a potential second BFS (or FFS for that matter) should be placed at around 30 mm downstream the BFS which correlates to 3 times the step height for the ULB campaign. The ULB and 2D slab burner campaigns both show increased regression rate profiles after the step, with the ULB campaign having a length-to-height ratio of 2.5x higher than the HYCAT campaign. The area of influence of the FFS (50 mm) is higher than the fuel grain length (118 mm), suggesting that distributing multiple FFS in longer fuel grains can add up their individual zone of influence to have a considerable effect on the space and time averaged regression rates. These areas of higher regression rates correspond to both cylindrical test campaigns and two-dimensional slab burner campaigns. The feasibility of BFS and FFS and their potential to increase the regression rate in HREs have been proven on three different experimental set-ups. Pressure oscillation is less a concern for the BFS cases and more for the FFS cases.

B. Liquid Propellant

Shrisudha Viswanathan, et al, works on Liquid propellant, which is the most reliable propellant, but hybrid propellant can be considered in future reference [3]. Environment pollution and human safety are concerns, so green propellants such as ethanol, hydrogen, oxygen, kerosene, paraffin wax, HTPB, carbon nanotubes or graphene are considered. Ion exchange transfer is promising research where electrons of inert gases are collided with positive ions to produce thrust. Hydroxyl Ammonium Nitrate (HAN) is another high energetic liquid propellant are promising steps towards the future development of propellants. Abdalrahman Khaled Mohammad, et al, explored the applications of liquid hydrogen (LH2) in aerospace projects, followed by an investigation into the efficiency of ramjets, scramjets, and turbojets for hypersonic flight [7]. The results showed that the total carbon emissions over the lifecycle of LH2 were greater than conventional fuel. Study examined the sustainability of LH2 in scramjets by comparing the total carbon emissions in the life cycle of green, blue, and gray hydrogen against conventional kerosene fuel. A Life Cycle Assessment (LCA) assessment of LH2 was performed and revealed that Steam Methane Reforming (SMR) with biomethane produced 3.3kg of CO2 per kg of green H2 produced, while SMR with natural gas and CCS at 90% efficiency produced 1.5 kg. This confirms that the lifecycle emissions of green hydrogen produce more CO2 compared to kerosene. Hypersonic flight is likely to produce more NOx emissions than super or subsonic vehicles due to the greater temperatures reached in the combustion chamber.

Hypergolic bipropellants based on high-test peroxide (HTP) have traditionally been low-toxicity propellants, but their late-ignition performance restricts their potential use in high-precision auxiliary response thrusters. The complex H2O2/kerosene turbulent flow and combustion reaction are modelled by Sen Li, et al [6]. During the kerosene injection, the spray angle is 13°, the lasting time of atomization is 1ms. The combustion chamber can be divided into three zones: rapid high-temperature pyrolysis zone, oxidation zone and equilibrium flow zone. The initial excitation of kerosene reactions is a crucial link, and recirculated flow eddies enhance the free radicals of O/OH/H to diffuse into the pyrolysis region. In the exhaust plume, the flow repeatedly contracts and expands while gradually equalizing the pressure difference between the exhaust and the atmosphere. The peak values of static pressure, temperature, Mach number are almost evenly distributed along the plume axis, and the interval distances are 32 mm along the centreline of the axis.

Juan J. Hernandez, et al, examines the auto-ignition behaviour of several advanced liquid fuels (HRFs) when operating under dual mode with H2, CH4 and NH3 (LRFs) [14]. It has been performed under well controlled conditions in a constant volume combustion chamber and found that while the occurrence of cool flames appears to be independent of the nature of the LRF and its energy ratio, the main ignition delay time increases with the amount of LRF. Ammonia showed a more significant effect on the autoignition time than methane and hydrogen, due to its previously documented sink effect and formation of stable intermediates (N2H4). Tests carried out by using HRFs with different DCN but similar chemical structure revealed that the higher the reactivity of the HRF, the lower the influence of the l RF. This result suggests that the use of cetane improvers may be beneficial for extending dual fuel operation towards LRFs with very poor autoignition properties.

C. Additives

Kyu-Seop Kim, et al, demonstrated the synergistic effects of new hybrid additives (reactive additive: catalytic additive, NaBH4:NaI,) on ignition performance [9]. Thermal analysis revealed that the hybrid additive improved thermal stability, and the theoretical vacuum-specific impulse was calculated. Study investigated the use of new hybrid additives to improve the IDT of HTP-based hypergolic propellants.

$NaBH_4$ and iodides (NaI and NH_4I) were proposed as promising candidates, and the fuels EDA, PDA, and DMA containing the hybrid additive exhibited a short IDT of less than 4 ms with 95 wt.% H_2O_2. Images of the hypergolic combustion of fuels revealed that the ignition processes took place via a gas-phase reaction, which is advantageous for reducing the IDT. The vacuum-specific impulse of the fuels was above 310 s, which is in the range of conventional hypergolic fuels.

D. Composite Propellant

Composite solid propellants (CSPs) are used as the main energy source for propelling rockets in both space and military applications. Khevinadya Ramadhani Runtu, et al, investigated the developments related to the use of highly energetic materials as raw materials for composite propellants for defence rockets [4]. The Rocket Technology Research Centre, ORPA-BRIN is developing a smokeless propellant composite with a composition based on the energetic materials AP/HTPB/Al and an oxidizing agent RDX. The combustion simulation software ProPEP and RPA shows that the composition of the resulting combustion gaseous (Al_2O_3 and HCl) shows a decrease when using RDX energetic material-based propellant. Metal oxides (MOs), complexes, metal powders and metal alloys have shown positive catalytic behaviour during the combustion of CSPs. Nanoscale catalysts improves the combustion characteristics of propellants due to their superior catalytic properties and large surface-to-volume ratio and quantum size effect. The combustion chemistry of a typical CSP is briefly discussed for providing a better understanding on the role of combustion catalysts in burning rate enhancement. Combustion catalysts have a great role in propellant technology, and nano catalysts in nanoscale size have been found to be more attractive for advanced solid rocket missions. Narendra Yadav, et al, has focused on synthesis, characterization, augmentation of oxidizer decomposition and efficacy in propellant combustion, but the findings and results available from these studies are often fragmentary and intensive work is needed to develop an understanding of the most attractive preparation approaches and mechanism of catalytic activity [12]. The process of preparation of nano-catalysts significantly influences their catalytic efficacy, and research and development work is needed to produce nano-catalysts suitable for propellant combustion. Standards for characterization of such materials need to be finalized to compare their physio-chemical properties, surface morphology, particle shape and size, and thermal decomposition behaviour of oxidizers. Burning rate results on various nano-catalysed CSPs are investigated, and significant influence of catalysts has been demonstrated.

E. Novel Propellant

Stefania Carlotti, et al, proposes a ranking of suitable figures of merit for novel propellant that aim at substituting hydrazine/NTO-based systems [8]. The main goal of the study was to derive a consistent and quantitative set of criteria that could lead to a systematic and simple selection methodology. Toxicity has been evaluated considering both health hazards and soil/water potential contamination caused by the chemicals during the propellant lifecycle. Performances in terms of vacuum and density specific impulse have been included. The intrinsic characteristics of the analysed propellants have made clear the absence of an optimal propellant couple and the need for a careful identification of mission and operational requirements to guide the selection.

III. BIO-FUELS

In addition to hydrazine and its derivatives as fuel, spacecraft have been using di-nitrogen tetroxide-based oxidizers and standard hypergolic propellant mixtures. However, due to their high toxicity and propensity for cancer, research into alternative green propellants is a rising field. In order to study two hypergolic room-temperature ionic liquids, 1-ethyl-3-methylimidazolium thiocyanate (EMIM SCN) and BMIM SCN, 96.1% hydrogen peroxide was used by Felix Lauck et al. [21]. The two ionic liquids' theoretical performance was evaluated, and the ignition delay time was shortened by dissolving a catalytic component. Study investigated ionic liquids containing the thiocyanate anion as hypergolic fuels with highly concentrated hydrogen peroxide. The theoretical performance of two different green propellant combinations was determined using two commercially available ionic liquids as fuel and 98% hydrogen peroxide as the oxidizer. Hydrogen peroxide at a concentration of 96.1% displayed hypergolic activity in drop testing with the two ionic liquids. The average ignition delay times for EMIM SCN and BMIM SCN were 31.7 ms and 45 ms, respectively. To shorten ignition delay periods, a catalytic ingredient was dissolved. With a Cu SCN content of 5 wt%, a minimum ignition delay time of 13.9 ms was discovered for the fuel. The duration of the gas phase reaction decreased with increasing copper additive amount, as was the time before vapor production. Thiocyanate ionic liquids were shown to be hygroscopic with extremely concentrated hydrogen peroxide with a brief ignition delay on the order of tens of milliseconds by thermogravimetric analysis and Fourier-transformed infrared spectroscopy (FTIR). They are prospective substitutes for hypergolic propellants in orbital propulsion systems since the calculated performance of the ionic liquids in terms of Isp and Isp is comparable to or superior to that of conventional hazardous propellants.

M. Mofijur, et al. look into the feasibility of using second-generation feedstocks based on the properties of fatty acid-based fuel to produce sustainable aviation fuel [20]. With Ricinus communis ranked as the top feedstock, 20 of the 38 feedstocks were determined to meet international fuel standards. Using international fuel standards, 38 non-edible feedstocks for the production of SAF were assessed in this study. However, due to a variety of fatty acid-based properties, untreated biofuel from these sources does not necessarily meet international aviation fuel criteria. For the commercialization of sustainable biofuel production in the aviation industry to be successful, additional experimental work is required to alter the properties of second-generation biofuel and ease current jet fuel standards. The physical and chemical characteristics of green monopropellant propulsion systems were evaluated in this study, and it was found that AND (LMP-103S) is preferred to hydrazine and hydrogen peroxide in terms of adiabatic decomposition temperature. Because of a special property, hydrogen peroxide is interesting for enhancing overall system performance and size optimization. Using techno-economic analyses, Abdul M. Petersen, et al. investigated different refinery designs for sustainable aviation fuels (SAF) derived from bioethanol or Fischer-Tropsch bio-Syncrude [27]. Synthetic aromatics had the highest efficiency and cost-effectiveness compared to the basic Syncrude refining, which had the lowest efficiency and CAPEX. The most effective way to increase the production of liquid fuel was by aromatizing the LPG gases; as a result, this method could withstand the most expensive Syncrude pricing. The Hybrid or PNNL oligomerization configurations, which achieved efficiencies of 77–80%, were the best for refining ethanol into aviation fuel. Costs were cut by 20% when the Heveling ethanol refinery was enhanced with a secondary reactor for higher selectivity towards aviation fuel. Unfortunately, the increased capital requirements could not be justified because the increased process complexity increased energy consumption, which in turn decreased product output. Energy recovery methods, like electricity produced by an Organic Rankine Cycle, were beneficial since they increased efficiency and commercial viability.

The combined analysis of pure palm-based wax to produce a solid fuel for a hybrid rocket engine is described by M. Tarmizi Ahmad, et al [26]. Rates and regression thrust can be attained even in pure-tested wax. On this novel fuel formulation, calorie analyses and ballistic experiments were carried out. About fuel made from palms that can be utilized in hybrid rocket engines with high regression rates. The sample made up of Paraffin Wax and Beeswax has a larger caloric value than pure paraffin wax, and the Stearic Acid/GOX regression rate is marginally lower than the HTPB/LOX regression rate. With the exception of composition-3, all test shots show external exhaust fuel burning with ambient oxygen contact. The tested fuel's impulse falls within the capabilities of a standard hybrid rocket. Although, there is a modest reduction in engine performance, the use of biodiesel in a rocket engine may produce outcomes similar to those of the conventional RP-1, this was investigated by G. Rarata, et al [25]. Biofuel is denser than conventional rocket fuel, biofuel rockets may be able to carry more cargo for the same volume of a rocket tank. Unburned hydrocarbons and CO emissions, two important pollutants, have decreased dramatically in exhaust concentration, whereas NOX has increased by 9%. Siti Chairiyah Batubara, et al, intends to develop alternative space rocket fuels with a powerful but affordable thrust for rocket technology made of rice straw and leftover cooking oil [24]. To assess the potential of the raw materials, a pilot phase of fuel generation was carried out. The two stages of testing's outcomes demonstrated that the mixture of used cooking oil, rice straw, and liquid oxygen as an oxidizer may be used as an alternative rocket fuel that is comparatively safe, affordable, and powerful. The reduced cellulose content of rice straw fibres makes it impossible to make nitrocellulose, according to tests for the generation of fuel. Because of its susceptibility to heat and shock, nitro-glycerine cannot be manufactured from the raw ingredients. Combustion experiments were performed after producing three refined goods. Cooking oil fuel was successfully collected and converted into solid form, however the needed steam spilled through the heated kettle cracks. With the most durable machine being made of steel, static tests assess rocket thrust utilizing pressurized oxygen cylinders, oxygen hoses, test bases, and rocket engines. The R9 engine can launch spacecraft without the aid of gravity since it has the highest thrust-to-weight ratio and the largest load capacity.

Pablo Cruz-Morales, et al. have studied Hydrocarbons; Hydrocarbons functionalized with cyclopropane are great fuels, but organic synthesis is difficult [23]. In order to create polycyclopropanated fatty acids in bacteria, which can then be transformed into new fuels for energy-intensive applications like shipping, long-distance travel, aviation, and rocketry, researchers found and reused naturally occurring cyclopropane compounds. An ACP-bound polyketide intermediate can be functionalized into burnable molecules by being released as a carboxylic acid, however during the production of jaw-samycin, it is condensed with a uridyl moiety by the aminotransferase Jaw. Either find and exploit a novel polycyclopropanating iPKS (POP-iPKS) pathway that naturally contains a TE to make a carboxylate or insert a thioesterase from a known pathway to the jawsamycin pathway in order to produce a POP fuel. With the exception of filamentous actinobacteria and an unidentified member of the phylum Chloroflexi, the taxonomic distribution of the POP BGCs is nearly entirely restricted to Streptomyces. Pop1 is an iPKS with domains for dehydrase, acyltransferase, keto-synthase, and ACP.

Pop3 is a solo ketoreductase, whereas Pop2 is a stand-alone, SAM-dependent CP related to the HemN-like coproporphyrinogen III oxygenase family (KR). Pop4 is a stand-alone TE that belongs to the Hot Dog protein family, and the fact that 70% of POP BGCs have genes encoding TEs suggests that POP-iPKS systems frequently have a free carboxylate intermediate or product. POP BGCs discovered a BGC in Streptomyces albireticuli NRRL-B1670 that encodes unique lipid and FA biosynthesis, pointing to a role in membrane modification involving CP molecules.

IV. SPACE SUSTAINABILITY

In order to maintain space activities and reduce their negative effects on the environment, both on earth and in space, a sustainable approach is necessary. The long-term sustainability implications of expanding space activity are examined by Elena Cirkovic, et al. with the emphasis on orbital debris [36]. The Space Sustainability Rating (SSR) is a voluntary method designed to promote current, globally recognised space debris mitigation strategies, while also enhancing transparency and highlighting their approach to debris mitigation. It complements the LTS Guidelines, which describe the potential to continue space activities indefinitely as long-term sustainability of outer space activities. The SSR supports the following areas: policy and regulatory framework, safety of space activities, international cooperation, capacity building and awareness, and scientific and technical research and development. By better space object registration techniques, accurate orbital data, and conjunction assessment, SSR is a helpful incentive for guaranteeing the long-term sustainability of the space environment. M. Palmroth, et al. summarizes the discussions that took place at the First Sustainable Economy Workshop and focused on the economic, technological, and legal aspects of sustainable space use [31]. Two concepts, orbit capacity and satellite sustainability footprint, are already under development. A third metric is an overall global benefit that can be determined from different satellite compositions. To further explore the evolution of orbit utilization regimes, an assessment of the distinctions between regulatory and non-binding, "self-organizing" processes is necessary. Two examples of bottom-up processes are the World Economic Forum's Space Sustainability Rating and the continuing procedure for on-orbit servicing standards. Also, a suggestion for a bottom-up strategy based on market prospects for sustainability is made, including in-orbit servicing, active debris removal, and debris mitigation. Due to potential regulations for clearing the orbit space that may follow, there is a business opportunity for the development of deorbiting technologies. Y. Fabignon, et al. reviews recent studies conducted at ONERA within the framework of solid rocket propulsion for missiles, as well as space launchers [11]. Three major scientific topics were investigated: combustion of solid propellants, motor interior ballistic, and rocket exhaust plumes. The physical phenomena observed in a SRM chamber and in an exhaust, plume are complex and involve interactions between chemistry, acoustics, turbulence, two-phase flows and radiative effects. Research is being carried out to predict the behaviour of solid rocket motors and their interaction with the atmosphere.

Augustin Chanoine, et al. describes The ESA project demonstrated that Life Cycle Evaluation was a significant and useful technique for analysing the ecological effects, that it was applicable to a space mission's whole life cycle, and that it could very well be used in the real world [34]. An early version of a database containing environmental data on materials, procedures, tools, and activities particular to the space industry was also able to be created thanks to the pilot LCAs, which helped to identify the environmental hotspots of space missions. For the eco-design of space missions, ESA is now developing IT and methodological tools that will be put to the test at CDF in the next months. Designers will benefit from the eco-design tool's assistance in understanding their environmental impact. Sahba El-Shawa, et al. studied the efficient and prompt implementation of solutions in order to ensure for a more sustainable use of space, the European Space Agency (ESA) established the Clean Space office [29]. It primarily engages in three activities: eco-design, end-of-life management, and in-orbit maintenance (IOS). IOS encompasses any operations that could be performed in orbit to secure the long-term utilization of space, such as active debris removal or in-orbit refuelling and recycling. Assessing how space missions would affect the ecology on Earth is the main goal of eco-design. The development of technologies that will reduce the likelihood that a spacecraft may end up as debris in the future is connected to the management of end-of-life. By the assessment, mitigation, and restitution of environmental impacts, ESA Clean Space and its three components—Eco Design, EoL Management, and IOS—promote sustainability in space. While Eco Design initiatives are focused with environmental ramifications and green technologies, EoL management focuses on reducing space trash. IOS actively clears space trash from orbit while displaying in-orbit maintenance technologies. These initiatives support the LTS standards and UN Goals.

Tatyana Koroleva, et al. examines the effects of the Proton and Soyuz Russian launch vehicles (LV) on the terrestrial ecosystems in Central Kazakhstan and the Altai-Sayan region [28]. Local effects of the LV operation on the ecosystems of different stages dropping regions, including mechanical, chemical, and pyrogenic effects (FR). Nitrogen tetroxide (NT) and unsymmetrical dimethylhydrazine (UDMH) propellant component leaks as well as damage to the soil and vegetation cover are included in this (UDMH).

The Proton first stage FS snow was where UDMH was largely discovered, and there, its concentration might reach up to 2200 mg/dm3. In the NT leaking zones, NO3 concentrations increased to as high as 22.3 g/dm3 in the snow and 24.8 g/kg in the soil, while pH values increased to 10.3 and 9.4, respectively, and background values varied from 5.1 to 7.3. The anthropogenic effects of space flight on terrestrial ecosystems include noise, light, heat, chemical, mechanical, fire, and pollution of ecosystems with fragments of dead stages. The most important facts are the propellant components' and their products' short-term and much bigger chemical influence on ecosystems. The mechanical impact area in the Soyuz-FG first stage FS was 1.5 times larger than in Proton-M situations. Also, the structure and production of phytocoenosis are altered by the mechanical disturbances multiplied by seven by a huge truck utilized for the evacuation of stage debris. The ecosystem will hardly be impacted if the launches take place in the winter. Tyler M. Harris, et al, examined the use of sustainability tools for space activities through a case study comparing the cost and environmental impacts of the SpaceX Falcon 9 and Falcon Heavy systems [32]. According to the study, the Falcon 9 and Heavy systems' reusable architecture decreased effects by 58% while cutting producer costs by over $6,000/kg to GEO. While non-carcinogens, ozone depletion, and producer cost impacts all showed significant improvement (>65%), the impact category for the depletion of fossil fuel resources showed the least improvement (37%). The manufacturing of the infrastructure and tools for spacecraft/rocket launch accounts for the majority of the effect potential. Although the Falcon Heavy system is a super heavy-lift launch vehicle capable of carrying over 50,000 kg to LEO, smaller payloads, such as humans, may be more effective at reaching LEO or below. Both LCA and S-LCA would need to be upgraded to better quantitative sustainability analyses for activities in space. To translate the LCI data into relevant environmental implications, such as potential for global warming, resource consumption, water quality, air quality, and land use, LCIA would need new methodologies. It is necessary to create and use standardized LCIA impact categories and characterization techniques. Five key stakeholder groups can be taken into account to make the Social LCA more easily adaptable for space activities. Findings demonstrated that SpaceX's development of the Falcon Heavy reusable rocket technology resulted in considerable reductions in all assessed environmental and financial consequences.

Volker Maiwald, et al. discusses the importance of technology advancement in human spaceflight to sustainable development [35]. Technology-driven ecological footprint reduction is one approach to attain sustainability, and human spaceflight can supply technology for terrestrial uses. As a research institution to create closed-loop technologies and unite stakeholders in the spaceflight and terrestrial industries, the Incubator for Habitation has been proposed. It has been suggested that the two research communities be combined to maximize the effects of the respective technical developments.

S Drobyazko, et al, explains Sustainable space activities, including their needs, technologies, and procedures to prevent the accumulation of objects in orbit, as well as blockchain technology to safeguard space objects [30]. To avoid harmful environmental effects and mitigate them, environmental management systems are required. The aerospace sector is a crucial infrastructure, and it is important to enhance the security features of commercial companies and academic institutions engaged in space operations, according to the findings of the SWOT analysis. Blockchain technology holds great promise for the space industry since it makes it possible to integrate communications into a single system and monitor the course of space objects online. Companies can use agile management to accelerate the development of new products and services while reducing costs and improving the quality of their current offerings. To lessen the knowledge imbalance that can result in the Kessler effect and the unsuitability of near space for human usage and colonization, information and communication support are crucial.

Tatiana Arkhipova, et al, describes the non-digital corporate culture, people's conservatism, and the desire to keep things the same are what make digital transformation for the rocket and space industry firms so challenging [33]. By updating management algorithms, restructuring corporate culture, rearranging business processes, and creating new technology regulations, the primary job is to make the transition to digitalization principles. To ensure the industry's continued development, this is essential. The World Bank Publication Business Strategy for Sustainable Development: Leadership and Responsibility provides a condensed understanding of the concept's guiding concepts and rules. Enterprises in the rocket and space industries must assure the stability of three key factors: economic, environmental, and social, in order to maintain a leadership position in the field of space technology. The execution of a significant project built on the innovations of the Russian Space Systems holding, a subsidiary of the Ros cosmos State Corporation, encourages the growth of the national economy. In terms of agriculture and forestry, land registration, cartography, region administration, control and prevention of emergencies, natural disasters, and man-made mishaps, the project offers qualitatively new opportunities. The market for geographic information systems (GIS) and satellite remote sensing has been gradually expanding, and this initiative will eventually produce financial gains. N. N. Gorkavyi [19] discusses the Suomi limb profiler observations of aerosol trails remaining at altitudes of 30-65 km after rocket launches. It is possible to use these clouds as indicators in the analysis of wind transport in the stratosphere.

A new phenomenon of the ballistic transport of aerosol clouds, which appeared when the engines of rocket carriers were running, can be useful to study the wind transport of aerosols and consider the effectiveness of space engines under real conditions. A limb profiler, operating in 2−3 wavelengths, can be produced for a CubeSat-type satellite several kilo-grams in weight. A supported complex of several satellites of this type will provide optimal conditions to survey the atmosphere and observe natural and artificial aerosol clouds.

V. CONCLUSIONS

The Paper outlines, a comprehensive criteria system to evaluate the sustainable performance of AAFs can be quintessential to determine and rank the appropriate aviation fuels. Using Hydrogen Peroxide as an oxidiser in the solid fuel grains can improve the performance of the propellent equivalent to a liquid propellent, but the it comes with potential risk of explosions, autoignitions and thermal stability issue. Using Paraffin wax with additives like beeswax provide a larger calorific value than pure paraffin wax. 3D printing can be used to produce paraffin wax based fuel grain and some additives like Magnesium diboride and carbon black can help to increase the burning rate and mechanical strength of the fuel grain. To prevent inefficient combustion in aluminium based solid rocket fuels due to the oxide layer, sufficiently high temperature is required before igniting the aluminium fuel. Stepped hybrid solid fuel grains can be used to take advantage of the positive effects of BFS and FFS in hybrid rockets.

Alternative green propellants like ethanol, hydrogen, oxygen, kerosene, paraffin wax, HTPB, carbon nanotubes or graphene can be used in hybrid rockets to replace the liquid propellants considering the environmental impacts and human safety. Turbulent combustion model of one of the biofuels kerosene shows that it is capable of having evenly distributed static pressure, temperature and Mach number values along the plume axis. Use of new hybrid additives to improve the IDT of HTP-based hypergolic propellants. $NaBH_4$ and iodides (NaI and NH_4I) were proposed as promising candidates, and the fuels EDA, PDA, and DMA containing the hybrid additive R3(S) or R3(A) exhibited a short IDT of less than 4 ms with 95 wt.% H_2O_2

Smokeless propellant composite can be developed by using energetic materials like AP/HTPB/Al and oxidizing agent RDX.

Creating composite solid propellants for propulsion of rockets using nanoscale catalysts with metal powders and alloys can provide a better burn rate. Ionic liquids like 1-ethyl-3-methylimidazolium thiocyanate and hydrogen peroxide can be prospective substitutes for hypergolic propellants in orbital propulsion systems, as the ISP is comparable to or superior to that of conventional hazardous propellants.

Second generation feedstocks can be a potential option for a sustainable aviation fuel, but currently it does not satisfy the international aviation fuel criteria. However, altering the properties of biofuels is possible by treating them using certain scientific methods in the future. Bioethanol can be considered as a contender for a sustainable aviation fuel in the future, as the cost of producing refined bioethanol is not feasible at the moment. Using biofuels can be beneficial for carrying more cargo overboard as it occupies less volume than conventional rocket fuels. Cooking oil, rice straw, and liquid oxygen as an oxidizer may be used as an alternative rocket fuel for small scale rockets.

Regulations like Space Sustainability Rating can be used to enhance transparency in the space organizations and highlight their debris mitigation approach. Focusing on concepts like Life cycle Evaluation of a space mission, orbit capacity and satellite sustainability footprint developed by various organizations creates a positive impact towards a sustainable space environment. Using reusable rockets like Falcon 9 creates a substantial impact in terms of creating a sustainable launch vehicle of the future, having multiple advantages in terms of reduced cost of sending cargo in space and manufacturing costs as well as reduced ozone depletion. Technology-driven ecological footprint reduction is one approach to attain sustainability, and human spaceflight can supply technology for terrestrial uses. Sustainable space activities needs a blockchain to prevent accumulation of objects in orbit and to safeguard the space objects.

REFERENCES

[1] Riccardo Gelain, Artur Elias De Morais Bertoldi, Adrien Hauw, Patrick Hendrick “3D Printing Techniques for Paraffin-Based Fuel Grains” Springer Aerotecnica Missili & Spazio September 2022
[2] Nadir Yilmaz, Burl Donaldson, Walt Gill “Aluminum Particle Ignition Studies with Focus on Effect of Oxide Barrier” MDPI Aerospace January 2023
[3] Shrisudha Viswanathan, Karthika Chandramohan “A Review on the Development of Various Types of Rocket Propellants” International Journal of Science and Research (IJSR) Vol. 10 Issue 11, November 2021
[4] Khevinadya Ramadhani Runtu, Wahyu Sri Setiani, Mala Utami “Application Energetic Materials for Solid Composite Propellant to Support Defense Rocket Development” International Journal of Social Science Research and Review Vol. 6, Issue 1 January, 2023 Pages: 153-159
[5] Wioleta Kopacz, Adam Okninski, Anna Kasztankiewicz, Paweł Nowakowski, Grzegorz Rarataa, Pawel Maksimowski “Hydrogen peroxide – A promising oxidizer for rocket propulsion and its application in solid rocket propellants” FirePhysChem March 2022

[6] Sen Li, Yifei Ge, Xiaolin Wei, Teng Li "Mixing and combustion modeling of hydrogen peroxide/kerosene shear-coaxial jet flame in lab-scale rocket engine" Aerospace Science and Technology Elsevier July 2016

[7] Abdalrahman Khaled Mohammad, Charles Sumeray, Maximilian Richmond, Justin Hinshelwood, Aritra Ghosh "Assessing the Sustainability of Liquid Hydrogen for Future Hypersonic Aerospace Flight" MDPI Aerospace December 2022

[8] Stefania Carlotti, Filippo Maggi "Evaluating New Liquid Storable Bipropellants: Safety and Performance Assessments" MDPI Aerospace September 2022

[9] Kyu-Seop Kim, Vikas K. Bhosale, Sejin Kwon "Synergistic effect of a hybrid additive for hydrogen peroxide-based low toxicity hypergolic propellants" Combustion and Flame by Elsevier April 2021

[10] O.V. Romantsova, V.B. Ulybin "Safety issues of high-concentrated hydrogen peroxide production used as rocket propellant" Acta Astronautica by Elsevier October 2014

[11] Y. Fabignon, J. Anthoine, D. Davidenko, R. Devillers, J. Dupays, D. Gueyffier, J. Hijlkema, N. Lupoglazoff, J. M Lamet, L. Tessé, A. Guy, C. Erades (ONERA) "Recent Advances in Research on Solid Rocket Propulsion" Journal Aerospace Lab Issue 11 - June 2016

[12] Narendra Yadav, Prem Kumar Srivastava, Mohan Varma "Recent advances in catalytic combustion of AP-based composite solid propellants" Defence Technology KeAi June 2020

[13] Naijie Chai, Wenliang Zhou "A novel hybrid MCDM approach for selecting sustainable alternative aviation fuels in supply chain management" July 2022 Fuel Elsevier

[14] Juan J. Hernandez, A. Cova-Bonillo, A. Ramos, H. Wu, J. Rodríguez-Fernandez "Autoignition of sustainable fuels under dual operation with H2-carriers in a constant volume combustion chamber" Fuel Elsevier January 2023

[15] Yash Pala, Sasi Kiran Palateerdham, Sri Nithya Mahottamananda, Subha Sivakumar, Antonella Ingenito "Combustion performance of hybrid rocket fuels loaded with MgB2 and carbon black additives" Propulsion and Power Research KeAi August 2022

[16] Faris M. AL-Oqla and Mohammed T. Hayajneh "Hybrid material performance assessment for rocket propulsion" Journal of the Mechanical Behavior of Materials April 2022

[17] Xiaodong Yu, Hongsheng Yu, Wei Zhang, Luigi T. DeLuca and Ruiqi Shen "Effect of Penetrative Combustion on Regression Rate of 3D Printed Hybrid Rocket Fuel" MDPI Aerospace November 2022

[18] C. Glaser, R. Gelain, A.E.M. Bertoldi, Q. Levard, J. Hijlkema, J.-Y. Lestrade, P. Hendrick, J. Anthoine "Experimental regression rate profiles of stepped fuel grains in Hybrid Rocket Engines" Acta Astronautica Elsevier December 2022

[19] N. N. Gorkavyi "Spaceborne Limb Observations of Artificial Aerosol Clouds" published in Kosmicheskie Issledovaniya, 2020, Vol. 58

[20] M. Mofijur, Shams Forruque Ahmed, Zahidul Islam Rony, Kuan Shiong Khoo, Ashfaque Ahmed Chowdhury, M.A. Kalam, Van Giang Le, Irfan Anjum Badruddin, T.M. Yunus Khan "Screening of non-edible (second-generation) feedstocks for the production of sustainable aviation fuel" Fuel Elsevier August 2022

[21] Felix Lauck, Jakob Balkenhohl, Michele Negri, Dominic Freudenmann, Stefan Schlechtriem "Green bipropellant development – A study on the hypergolicity of imidazole thiocyanate ionic liquids with hydrogen peroxide in an automated drop test setup" Combustion and Flame Elsevier November 2020

[22] Janani Kavipriya VS, Bhushan Chavan, Krithika, Boparai Manmeetkaur Ajmersingh "Comparative Study on Green Monopropellants for Rocket Engines" EDUZONE: International Peer Reviewed/Refereed Multidisciplinary Journal (EIPRMJ), Vol.11, Issue 1, January-June 2022

[23] Pablo Cruz-Morales, Kevin Yin, Alexander Landera, John R. Cort, Robert P. Young, Jennifer E. Kyle,6 Robert Bertrand, Anthony T. Iavarone, Suneil Acharya, Aidan Cowan, Yan Chen, Jennifer W. Gin, Corinne D. Scown, Christopher J. Petzold, Carolina Araujo-Barcelos, Eric Sundstrom, Anthe George, Yuzhong Liu, Sarah Klass, Alberto A. Nava and Jay D. Keasling "Biosynthesis of polycyclopropanated high energy biofuels" Joule Cell Press July 2022

[24] Siti Chairiyah Batubara, Fahrul Nurkolis, Nelly Mayulu, Dewa Baskara Gama "Alternative Fuels For Rocket Based On Household Waste From Used Cooking Oils And Rice Straw" International Journal of Creative Research Thoughts (IJCRT) Vol. 8, Issue 12 December 2020

[25] G. Rarata, P. Surmacz "The Analysis of Use of Liquid Biofuels for Liquid Rockets Propulsion"

[26] M. Tarmizi Ahmad, Razali Abidin, A. Latif Taha, Anudip and Amzaryi "Feasibility Study of Palm-Based Fuels for Hybrid Rocket Motor Applications" International Conference on Engineering and Technology (IntCET 2017) Feb 2018

[27] Abdul M. Petersen, Farai Chireshe, Oseweuba Okoro, Johann Gorgens, Johan Van Dyk "Evaluating refinery configurations for deriving sustainable aviation fuel from ethanol or syncrude" Fuel Processing Technology Elsevier May 2021

[28] Tatyana V. Koroleva, Pavel P. Krechetov, Ivan N. Semenkov, Anna V. Sharapova, Sergey A. Lednev, Andrey M. Karpachevskiy, Andrey D. Kondratyev, Nikolay S. Kasimov "The environmental impact of space transport" Transportation Research Part D Elsevier

[29] Sahba El-Shawa, Benedetta M. Cattani, Luisa Innocenti, Jessica Delaval "From Cradle to Grave: ESA Clean Space's Approach to Space Sustainability" 72nd International Astronautical Congress, Dubai in 2021 by European Space Agency.

[30] S Drobyazko and T Hilorme "Influence of Sustainable Development of Space Activities on Earth Ecology" JESSD 2021 IOP Conf. Series: Earth and Environmental Science

[31] M. Palmroth, J. Tapio, A. Soucek, A. Perrels, M. Jah, M. Lonnqvist, M. Nikulainen, V. Piaulokaite, T. Seppal, J. Virtanen "Toward Sustainable Use of Space: Economic, Technological, and Legal Perspectives" Space Policy Elsevier May 2021

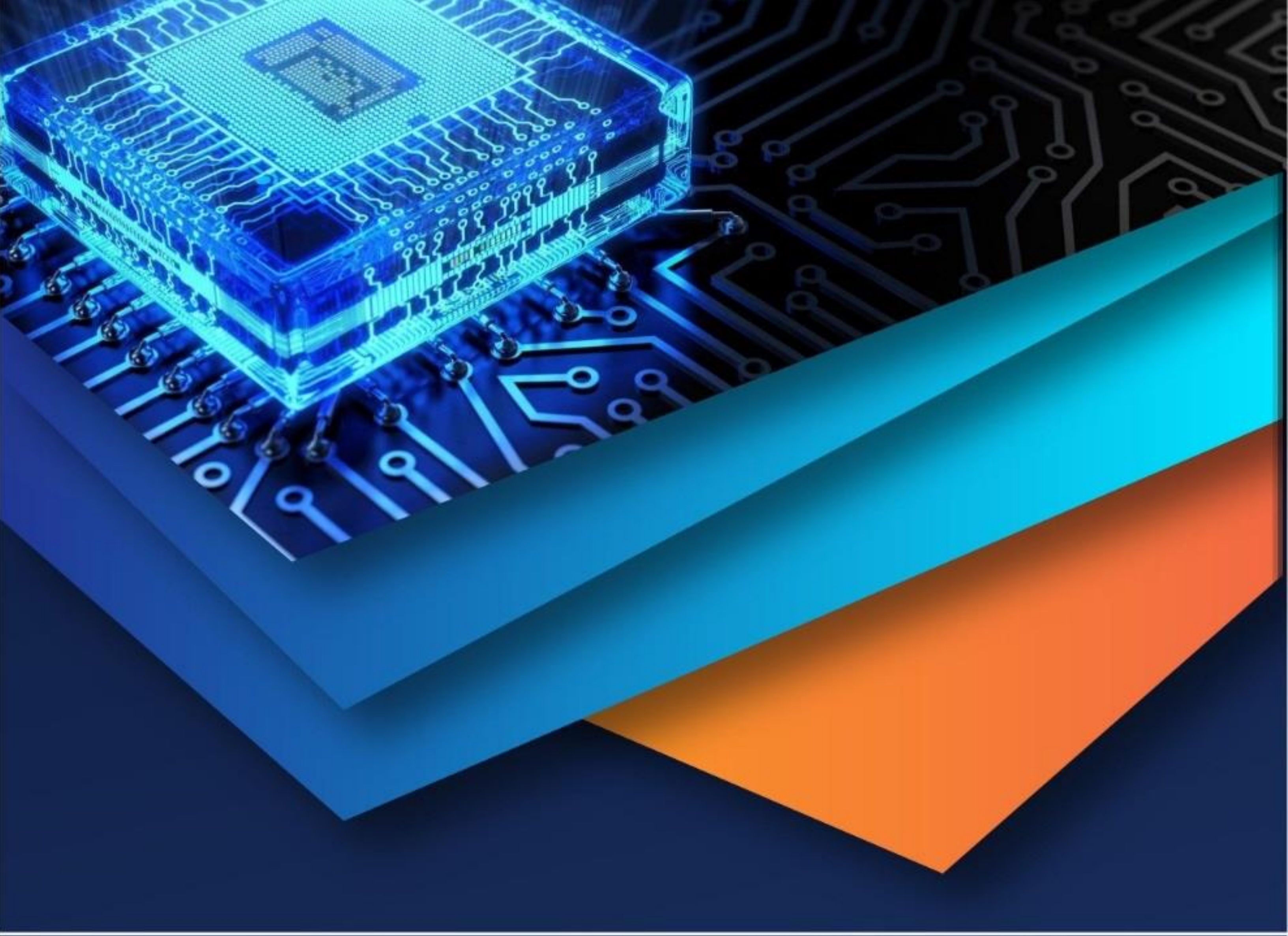
[32] Tyler M. Harris & Amy E. Landis "Space Sustainability Engineering: Quantitative Tools and Methods for Space Applications"

[33] Tatiana Arkhipova and Margarita Afonasova "Sustainable Development as a prerequisite of digital transformation of enterprises in rocket and space industry" 1st International Scientific Practical Conference "The Individual and Society in the Modern Geopolitical Environment" (ISMGE 2019)

[34] Augustin Chanoine, Yannick Le Guern, Francois Witte, Jakob Huesing, Tiago Soares, Luisa Innocenti "Integrating sustainability in the design of space activities: development of eco-design tools for space projects" Challenges in European Aerospace 5th CEAS Air & Space Conference

[35] Volker Maiwald, Daniel Schubert, Dominik Quantius and Paul Zabel "From space back to earth: supporting sustainable development with spaceflight technologies"

[36] Elena Cirkovic, Minoo Rathnasabapathy, Danielle Wood "Sustainable Orbit And The Earth System: Mitigation And Regulation" Proc. 8th European Conference on Space Debris (virtual), Darmstadt, Germany, 20–23 April 2021, published by the ESA Space Debris Office



10.22214/IJRASET

INDEX COPERNICUS

45.98

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089 (24*7 Support on Whatsapp)