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Original Research Article

Artificial intelligence and machine learning analysis of thrust efficiency factor of solid propellants for rocket applications

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ABSTRACT
2030 Vision of Saudi Arabia focus on creating a vibrant society focusing on Mining aerospace and other domains to establish economy-based infrastructures to enhance the human power of the nation. Space explorations related projects will lead to self-dependency in technological advances for civilian and defense applications. Hence it is clearly understood that the engineering projects in the domain of space explorations are of greater importance of the nation as per 2030 Vision. There is plenty of scopes for developing space technologies which in turn help to develop self and sustainable advances of the country in engineering domain. This work aims at developing a prominent solid propellent for rocket usages of the nation's space program. The first phase of the project focuses on obtaining critical composition of solid propellent namely dextrose and potassium nitrate to achieve optimal thrust efficiency for the rocket applications. Pro pep 3 software is used in calculation of the specific impulse of the solid propellent composition which is directly related to the thrust efficiency factor. Related optimization works prove that the composition namely 70% Potassium nitrate and 30% dextrose is offering maximum specific impulse.

1. Introduction

Solid propellent rockets are advantageous in fuel handling compared to liquid propellent rockets so that they are used in military and civilian applications [1-5]. Sucrose and dextrose based solid propellent systems are used widely as rocket fuel since they posses several advantages like low cost, high fuel handling capacity and no melting problems of combined solid propellent components etc. [6-10]. Among many solid propellants dextrose and potassium nitrate fuel combination have been researched extensively in recent times to use them as efficient solid fuels in rocket systems [11-13]. Artificial Intelligence and Machine learning techniques have gained enormous attention in recent times in optimizing many engineering processes so that ease of engineering applications is achievable n several industries [14-15].AI and Ml techniques are very well playing a crucial role in optimization processes of aerospace industries also to increase the efficiency of aerospace applications [16]. The study examines how propellant formulas and grain geometries affect solid propellant grain internal ballistic performance. For chamber pressure, temperature, thrust, and specific impulse, sucrose, potassium nitrate, and carbon were optimized using the Response Surface Methodology (RSM). Potassium nitrate increases the specific impulse, while sucrose and carbon concentrations decrease it. The best specific impulse was obtained with 0.584 kg sucrose, 1.364 kg potassium nitrate, and 0.052 kg carbon in a specified grain shape. Statistical analysis found no significant variation between anticipated and experimental ballistic characteristics. The bates grain design reduced combustion chamber oscillatory pressure best [17]. Another work addresses solid fuel rocket calculation analytically, focusing on mathematical functions. It shows how characteristic numbers rely on solid fuel grain length and how these approaches determine rocket caliber and fundamental parameters to get optimal values [18]. In semiprofessional rocket propellants like Candy, potassium nitrate, a solid rocket propellant chemical, has been studied. This inexpensive propellant has several advantages, including low production costs and facile chemical acquisition. But it needed enough experimental data to characterize its thermal properties. Candy propellant was professionally characterized by measuring heat of combustion, power, and melting/ignition temperatures using Differential Scanning Calorimetry and Semi-Micro Calorimetry [7, 18]. Solid-propellant rockets use fuel and oxidizer to create thrust. Modern rockets employ aluminum perchlorate, aluminum, HTPB, and isophorone diisocyanate, while their predecessors used solid fuel. Considering impulse, fuel and oxidizer, grain structure, and chemistry, sounding rocket propulsion systems are designed. The propellant weighs 960 kg, has a volume of 0.546176383 m^3, and measures 1.944787875 m [19]. Thrust coefficient, a key rocket performance measure, is examined in relation to expansion ratio and pressure ratio. The thrust coefficient is affected by gas properties, thermodynamics, and nozzle form. The study found that flow separation is typical when the exit pressure to atmospheric pressure ratio is below 0.25 to 0.35 and that propellant and nozzle design can reduce losses [20]. Black powder and sorbitol-potassium nitrate are tested as solid propellant rocket fuels. Gunpowder rockets had more height, thrust, and velocity than sorbitol-potassium nitrate rockets. Both fuels burned uniformly with identical rocket motors. Gunpowder rockets have higher centres of gravity and pressure, suggesting efficiency. Quantitative data on altitude, thrust, velocity, and trajectory were collected to identify tiny rocket fuel [21]. Recent ONERA research on solid rocket propulsion for missiles and space launchers is reviewed. The viewpoint explains physical phenomena using simulations, experiments, and modelling. It also discusses solid propellant combustion, motor internal ballistics with two-phase flows, turbulence, and radiative effects, and rocket exhaust plumes, including phenomena near the aft body [22]. Another work describes the EuRoc competition KNSB solid rocket motor design and optimization. The design method uses mass flow, isentropic flow, and correlations. Benefits, disadvantages, and manufacturing feasibility are considered while choosing propellant and grain form. Experimental results contrast with the theoretical model of the motor design [23]. The literature review clearly indicates that there is lots scopes left to concentrate in the research domain of developing solid propellent systems for rocket applications and optimizing the processes by utilization of artificial intelligence and machine learning techniques.

2. Experimental work

Formulation effects of various concentrations of the propellants namely dextrose and potassium nitrate are analyzed using Rocket Pro software. The same software is used in computation of the performance data of the rocket. Based on this analysis the rocket is designed using Solid works software. Artificial intelligence and machine learning algorithm of rocket performance are achieved for aforementioned conditions. This is carried out using PYTHON associated machine learning ORANGE software. The algorithm (decision tree) takes the peak mass flux as the primary variable to be analyzed with the variations of ratio namely solid propellent diameter to the core diameter.

3. Results and discussions

Figure 1 represents the formulation effect analysis on the performance of the ratio of solid propellent having ratio as 70/30. Various formulations of potassium nitrate and dextrose for propellent concentrations namely 60%&40%, 70%&30% and 80%&20% are analyzed. The analysis clearly indicates that the propellent concentration of 70% potassium nitrate and 30% dextrose give rise maximum specific impulse as 121.43 Ns/Kg. Fig.2 and 3 represents the performance analysis of the rocket with the variations of the ratio namely diameter of the propellent to the core dia. Variations of diameter of the propellent to the core diameter ratio is analyzed from 3.1 to 3.8. It is observed that the ratio of 3.7 leading to maximum impulse of 327.96 Ns for the considered solid propellent composition.

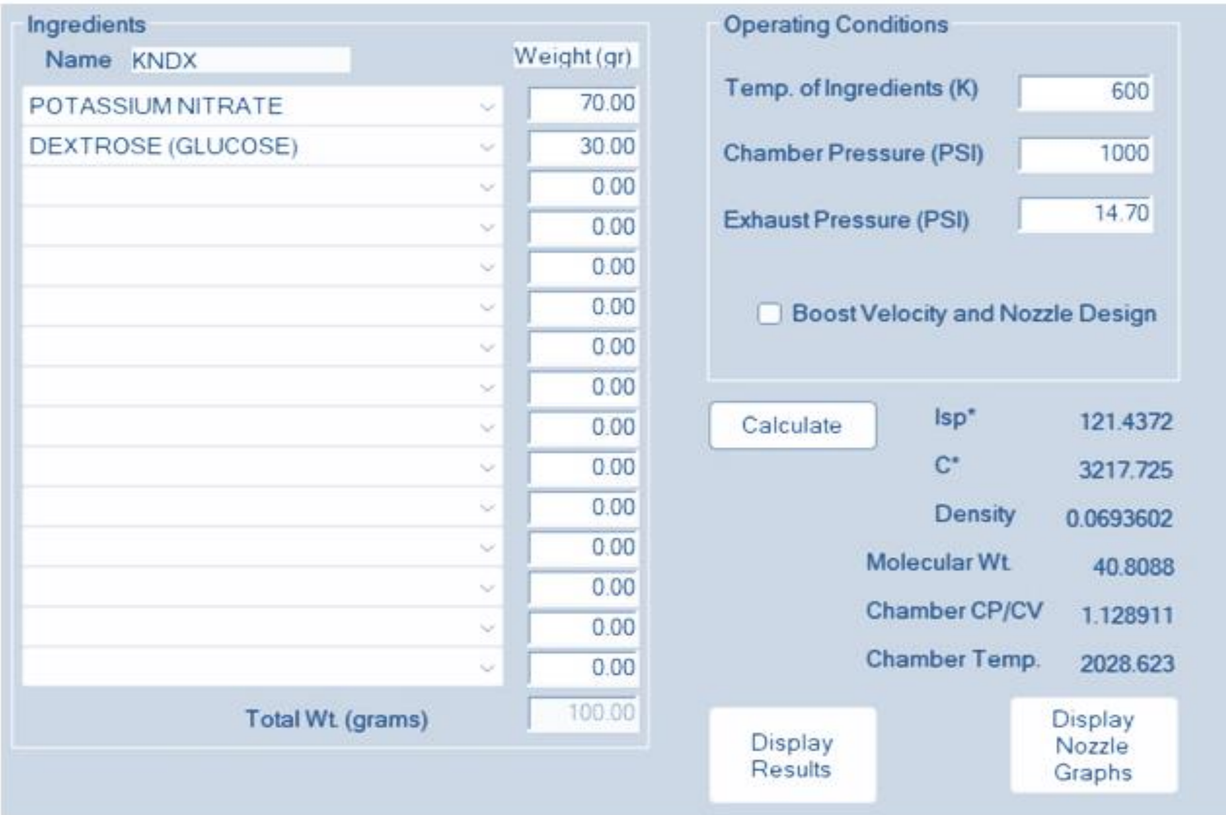

Figure 1: Formulation effect on the performance of the ratio of solid propellent having ratio as 70/30.

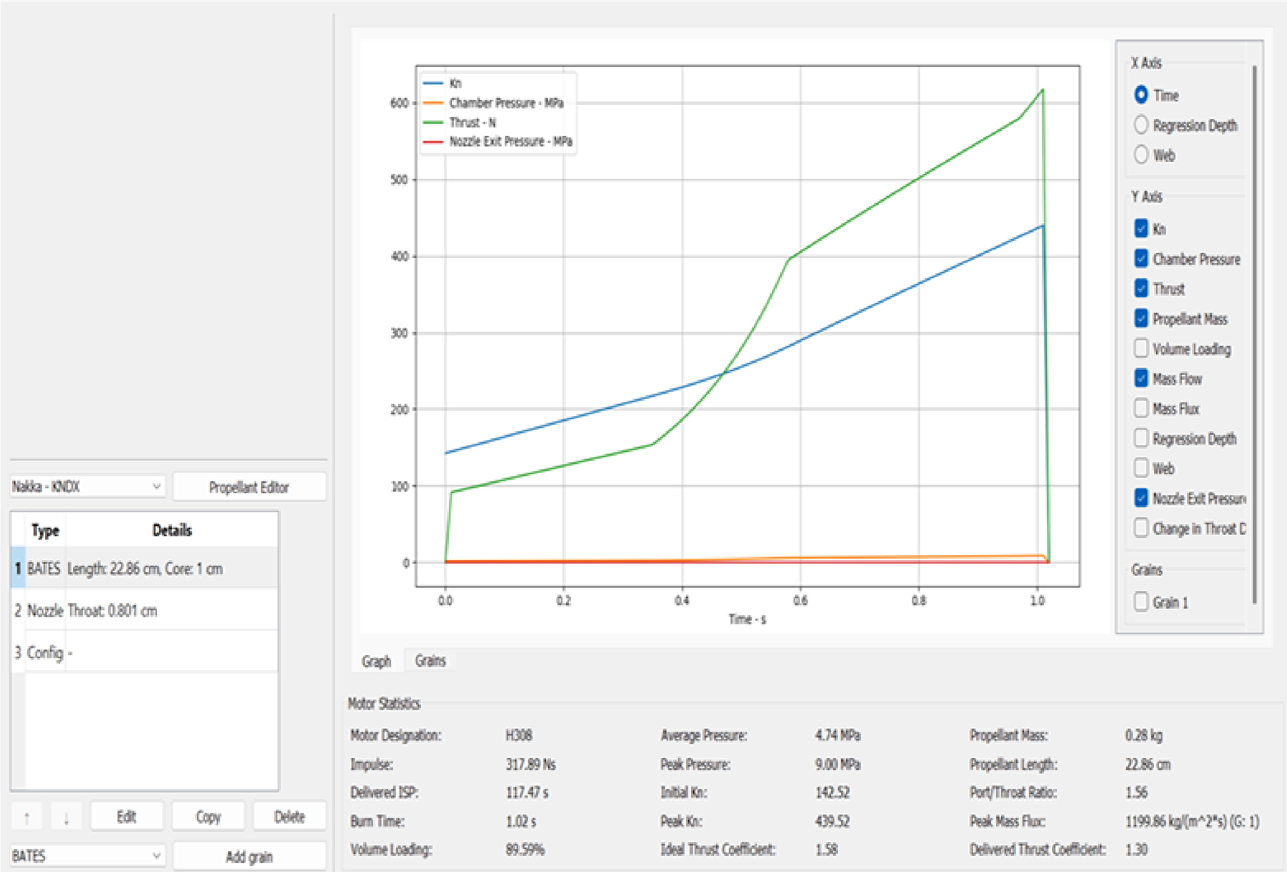

Figure 2: (a) Performance analysis of the solid propellent based on variations of ratio 3.1 namely diameter of the propellent to the core diameter.

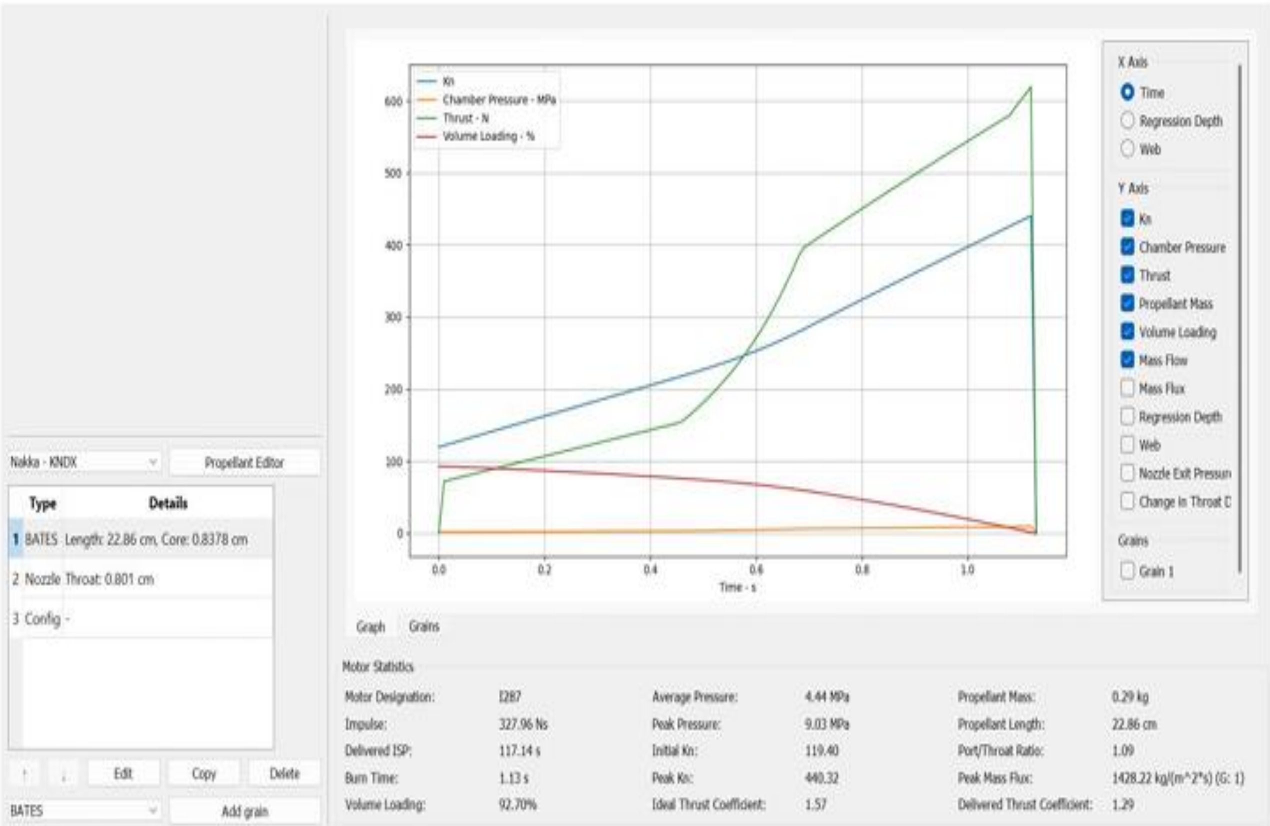

Figure 2: (b) Performance analysis of the solid propellent based on variations of ratio 3.7 namely diameter of the propellent to the core diameter.

Based on this analysis the rocket is designed using ANSYS software and presented in figure 3. Artificial Intelligence and machine learning analysis is carried out by feeding the software generated data in the formulation effect analysis and rocket performance analysis using ROCKET PRO software into ORANGE machine learning software.

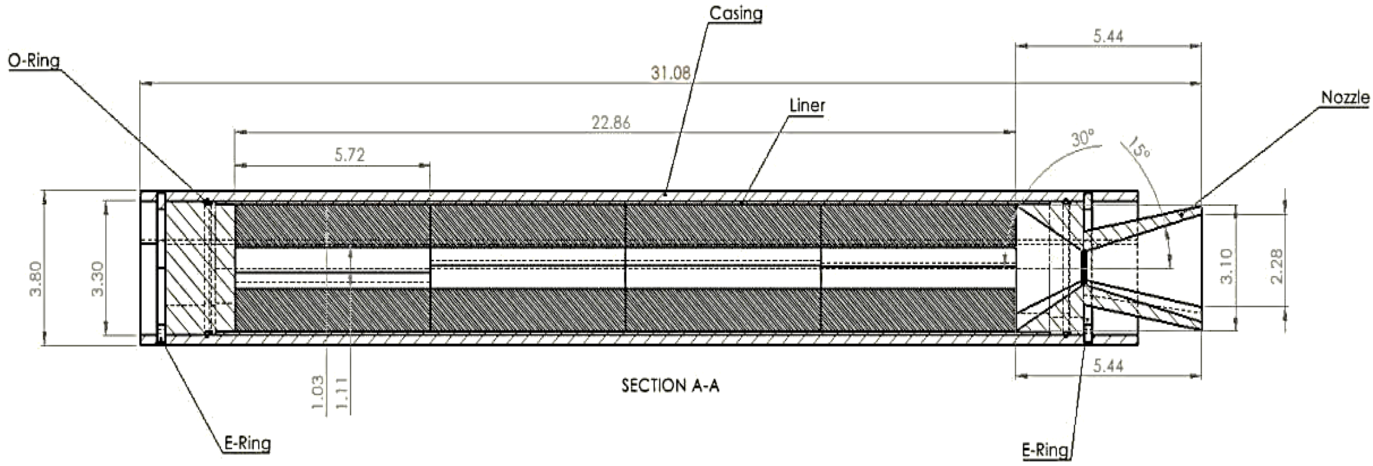

Figure 3: Rocket design in Solid works software based on analysis using Pro pep and Rocket pro software's.

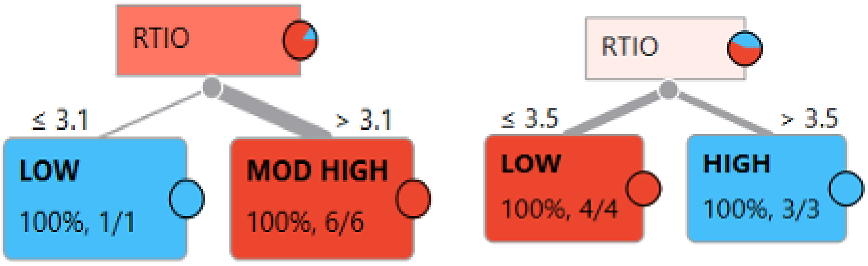

Figure 4: Artificial intelligence and machine learning analysis of rocket performance using AI and ML software for target parameter diameter of the propellent to the core diameter.

Figure 4 represents Artificial intelligence and machine learning analysis of rocket performance using AI and ML software for target parameter diameter of the propellent to the core diameter. It is clearly revealing that the ratio (RTIO) less than or equivalent to 3.1 is classified as "LOW" whereas the same is classified as Moderately high (MOD HIGH) when ranging from 3.1 to 3.5. The ratio greater than 3.5 are classified as "HIGH" by comparing the achieved data parameters during the software analysis.

Figure 5. represents the Artificial intelligence and machine learning analysis of rocket performance using AI and ML software for target parameter as average pressure (AVE PR). The critical average pressure to be classified in relation with other test parameters happens to be 4.71 MPa. When the AVE PR is greater than 4.71 the influencing parameter becomes the RTIO. It predicts that for the delivered impulse (DL ISP) of 118.49 Ns/Kg and the RTIO of 3.4 The maximum impulse of 326.9 Ns can be achieved.

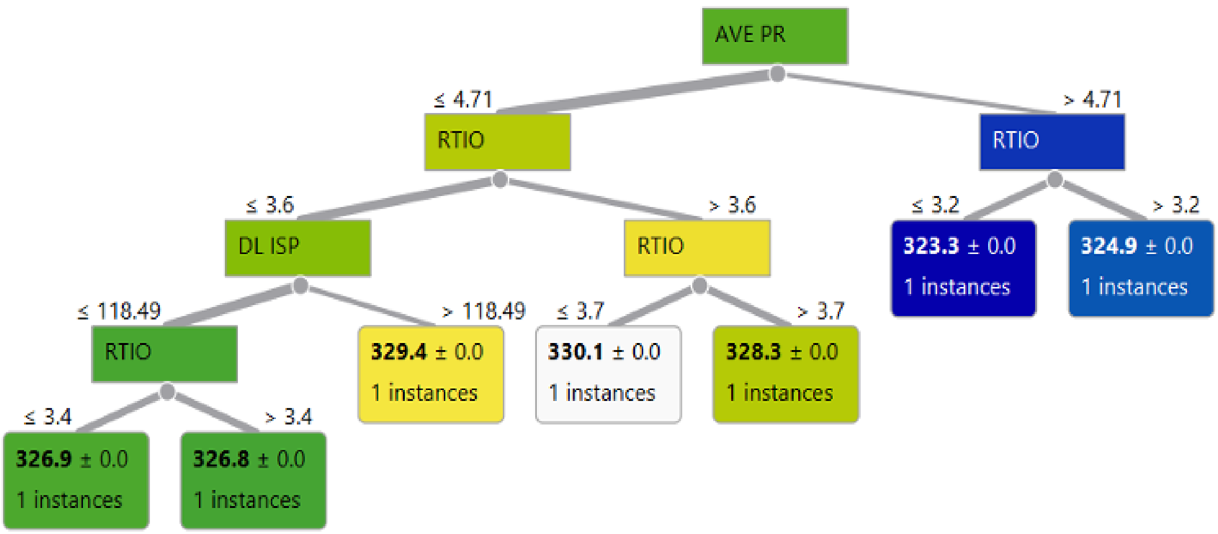

Figure 5: Artificial intelligence and machine learning analysis of rocket performance using AI and ML software for target parameter as average pressure.

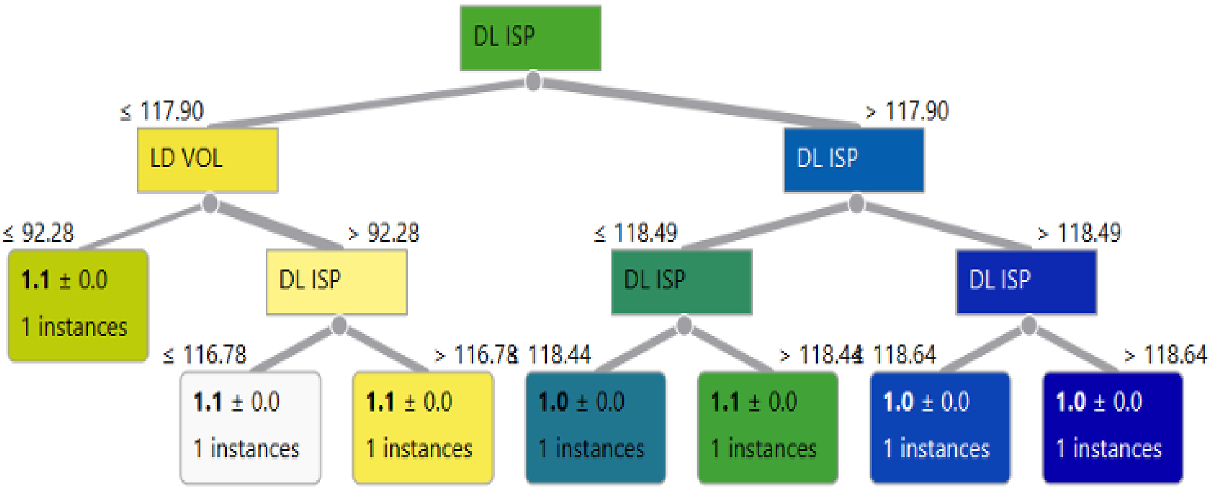

Figure 6: Artificial intelligence and machine learning analysis of rocket performance using AI and ML software for target parameter as delivered impulse.

Figure 6 represents Artificial intelligence and machine learning analysis of rocket performance using AI and ML software for target parameter as delivered impulse (DEL ISP). The critical DEL ISP for classification happens to be 117.90 Ns/Kg. When the DEL ISP is greater than 117.90 Ns/kg. The primary and secondary internal leaf nodes represents the variations port/ throat ratio nearly equivalent to 1. Whereas the for the DL ISP values less than or equal to 117.90 Ns/Kg, the connecting primary node parameter load volume (LD VOL) and the corresponding port/ throat ratio variations happens to be around 1.1.

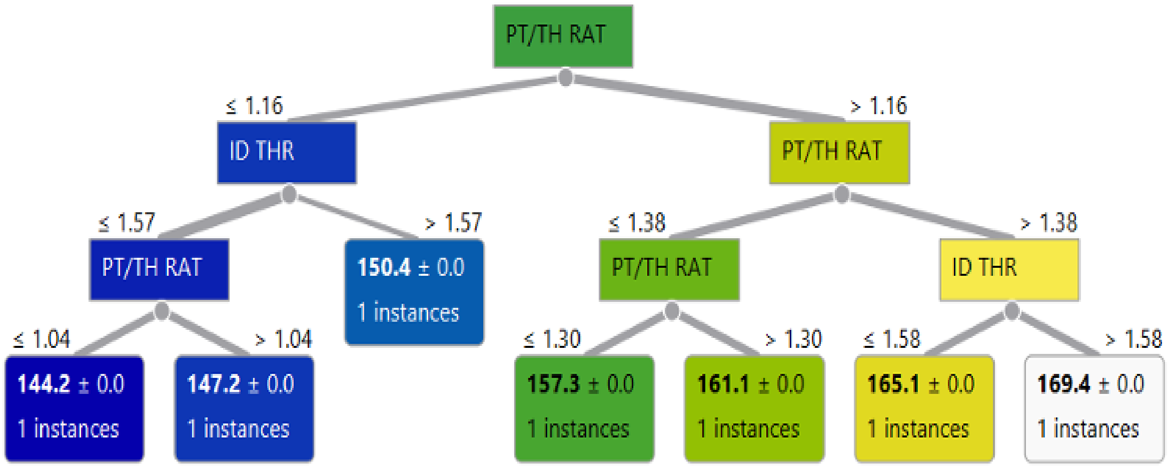

Figure 7: Artificial intelligence and machine learning analysis of rocket performance using AI and ML software for target parameter as port throat ratio (PT/TH RAT).

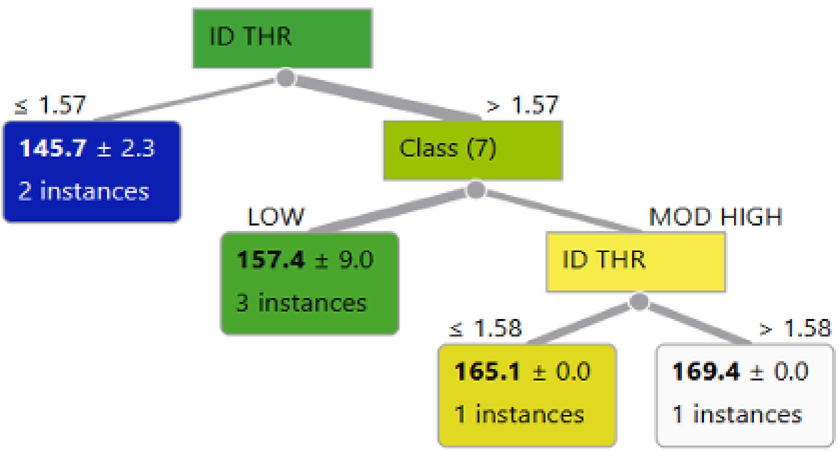

Figure 8: Artificial intelligence and machine learning analysis of rocket performance using AI and ML software for target parameter as ideal thrust (ID THR).

Figure 7 represents the Artificial intelligence and machine learning analysis of rocket performance using AI and ML software for target parameter as port throat ratio. The continuing AI and ML analysis show that the critical classification numerical value of PT/TH RAT happens to be 1.16. A value less than to the aforementioned one leads to initial Kn value representing burn surface area/nozzle throat area nearly equals to 150.4. Whereas PT/TH RAT is greater than 1.16 then the corresponding ID THR is elevated to 1.38 or more and resulting a high Initial Kn factor as 169.4.

Figure 8 represents Artificial intelligence and machine learning analysis of rocket performance using AI and ML software for target parameter as ideal thrust (ID THR). It is indicating that the critical numerical value of ideal thrust coefficient (ID THR) happens to be 1.57. It categorizes the ID THR as low when it is achieving burn surface area/nozzle throat area (Initial Kn) equivalent to 157.4 or less. It categorizes the ID THR as moderately high when it is achieving burn surface area/nozzle throat area (Initial Kn) equivalent to 165.1 or more. This indicates that to achieve higher Initial Kn the ID THR must be greater than 1.57.

4. Conclusions

The Artificial Intelligence and Machine learning Analysis of Thrust Efficiency Factor of Solid Propellants for Rocket Applications is successfully carried out. The analysis clearly indicates that the propellent concentration of 70% potassium nitrate and 30% dextrose give rise maximum specific impulse as 121.43 Ns/Kg. Variations of diameter of the propellent to the core diameter ratio is analyzed from 3.1 to 3.8. It is observed that the ratio of 3.7 leading to maximum impulse of 327.96 Ns for the considered solid propellent composition. AI and ML analysis of rocket performance for target parameter diameter of the propellent to the core diameter clearly reveals that the ratio (RTIO) less than or equivalent to 3.1 is classified as “LOW” whereas the same is classified as Moderately high (MOD HIGH) when ranging from 3.1 to 3.5. The ratio greater than 3.5 are classified as “HIGH” by comparing the achieved data parameters during the software analysis. The AI and ML test run predicts that for the delivered impulse (DL ISP) of 118.49 Ns/Kg and the RTIO of 3.4 The maximum impulse of 326.9 Ns can be achieved. When the DEL ISP is greater than 117.90 Ns/Kg, the primary and secondary internal leaf nodes represent the variations port/ throat ratio nearly equivalent to 1. Whereas the for the DL ISP values less than or equal to 117.90 Ns/Kg, the connecting primary node parameter load volume (LD VOL) and the corresponding port/ throat ratio variations happens to be around 1.1. When the PT/TH RAT is greater than 1.16 then the corresponding ID THR is elevated to 1.38 or more and resulting a high Initial Kn factor as 169.4. The AI and ML test output categorizes the ID THR as low when it is achieving burn surface area/nozzle throat area (Initial Kn) equivalent to 157.4 or less. It categorizes the ID THR as moderately high when it is achieving burn surface area/nozzle throat area (Initial Kn) equivalent to 165.1 or more. This indicates that to achieve higher Initial Kn the ID THR must be greater than 1.57.

Authors’ contributions

All authors contributed equally to the conception, design, data analysis, interpretation of results, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

Conflicts of interest

The author declares no conflict of interest.

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Data availability

No new data were created.

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