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Thrust Analysis of the RX-70 Rocket Using Burnsim Simulation with Variations in RDX Content and Grain Geometry

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Abstract: Indonesia, as the largest archipelagic country in the world with a strategic geographical position, has an urgent need to develop a reliable defence system, one of which is through rocket technology. The RX-70 rocket is one of the national rocket development programs designed to strengthen domestic defence capabilities. This study aims to analyze the thrust performance of the RX-70 rocket motor with a numerical simulation approach using BurnSim software. The main focus of this study is to evaluate the effect of variations in Cyclotrimethylenetrinitramine (RDX) content and star grain geometry configuration on the combustion characteristics and thrust performance of a rocket based on composite propellant containing Ammonium Perchlorate (AP), Aluminium (Al), and HTPB binder. The study was conducted quantitatively using simulations based on optimized propellant formulation data using ProPEP software. Variations in the number of star grains analyzed included configurations of 3 to 9 star points, with RDX content varying from 0% to 20% by weight. The simulation results showed that increasing the number of star grains contributed significantly to increasing the combustion surface area, which had a direct impact on increasing maximum thrust and reducing burn time. This shows that grain geometry has a dominant influence on motor performance compared to variations in RDX content in the tested range. On the other hand, the addition of RDX did not significantly increase thrust, but had an impact on combustion efficiency and the formation of condensed combustion products (CCPs). Higher RDX content tends to produce greater agglomeration of aluminium particles, which has an impact on decreasing combustion efficiency. The Star 8 configuration with the fifth variation showed the best performance, with the highest combustion chamber pressure reaching 753 psi and a stable thrust above 2,090 N. These findings emphasize the importance of grain geometry optimization in rocket motor design, as well as the need for a balance between energetic material content and combustion efficiency. This research contributes to the development of composite propellant design for national defence applications. To strengthen the validity of the findings, full-scale experimental testing is recommended to compare simulation results with actual performance in the field.

Keywords: BurnSim; RDX; RX-70 Rocket; Star-Grain Geometry; Thrust.

Introduction

Indonesia is a very advantageous geographical location, flanked by two continents (Asia and Australia) and two oceans (the Pacific and the Indian). Indonesia is the largest archipelagic country in the world. Due to its location, Indonesia borders on land and at sea with 10 countries, so that its seas are the main international trade routes. Due to this situation, Indonesia is vulnerable to border conflicts and security risks that can affect regional and national stability (Permenhan, 2012).

Maintaining territorial integrity, sovereignty, and public safety from various threats, national defence is very important. The military industry that produces the main weapons system (Alpahakam) with superior quality and in accordance with operational needs is one of the strategic resources that must be managed in order to build a national defence system (Ministry of Military of the Republic of Indonesia, 2020). The development of rocket technology is one of the main priorities that is very important considering Indonesia's very large territory and being separated by oceans [1].

The range of up to 7.8 kilometres, the RX-70 rocket, a modification of the 70 mm calibre FFAR rocket, is used for air-to-ground defence [2]. The nature of the composite propellant used has a significant impact on the performance of the rocket motor. Hydroxyl-Terminated Polybutadiene (HTPB) is usually used as a binder, aluminium (Al) as a metal fuel, and ammonium perchlorate (AP) as an oxidant in this propellant [3].

Figure 1. Roket RX-70

The addition of energetic materials such as Cyclotrimethylene Trinitramine (RDX), which has high energy content and stability, is considered to improve propellant performance, especially specific impulse (Isp) [4]. In addition to potentially increasing particle agglomeration and decreasing aluminium combustion efficiency, the

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addition of RDX can change the burning rate and thrust characteristics of the rocket motor [5].

BurnSim software is used in this study's simulation technique to assess how changes in star grain geometry and RDX content affect the thrust performance of the RX-70 rocket motor. It is important to note that these results are simulations, not laboratory or flight test results. The propellant mass in each formulation is also not exactly the same because the purpose of this study is to investigate how different star grain mould shapes affect relative thrust performance.

To help Indonesia's defence technology independence, this study aims to understand how changes in star grain geometry and RDX content affect thrust performance in the RX-70 rocket motor simulation. This knowledge will be the basis for creating a more ideal propellant design. To improve the performance of rocket motors, solid composite propellants with the addition of energetic materials such as RDX have been extensively studied. Banerjee and Runtu et al. showed that energetic materials can reduce smoke production during combustion and increase the specific impulse (Isp) [6][7]. According to Wulandari, replacing the oxidizer has an impact on Isp and smoke output, with ammonium perchlorate (AP) performing the best in several formulations [8].

The importance of optimizing design parameters in improving rocket performance is highlighted by studies on rocket performance, including those conducted by Oktaviani et al. and Wibowo et al., who used simulations using MATLAB Simulink and other software to analyze the effects of thrust profiles and flight trajectories [9][10].

Experimental studies by Chen et al. and Thomas et al. showed how propellant stability and burn rate are affected by particle size and nanocomposite material properties [11][12]. Meanwhile, studies by Williamson and Rice observed the mechanical response and behavior of RDX at high pressures, highlighting the complexity of high-energy material properties in harsh environments [13][14]. Overall, the studies show that changing the shape of the rocket motor and the composition of the propellant through simulation can produce accurate performance predictions and act as a basis for the creation of high-performance propellants.

By utilizing BurnSim simulations to analyze the combined effects of star grain geometry and RDX content variations on the RX-70 rocket, this study makes a unique contribution to the optimization of solid rocket motor performance. This study examines how grain geometry and energetic additives interact in a specific national rocket platform, unlike previous studies that focused on each topic separately. The main objective is to determine which component—geometry or energetic content—has a greater impact on impulse, chamber pressure, thrust performance, and specific burn time. Within the measured range, it is predicted that grain shape changes will affect thrust characteristics more significantly than RDX content. It is expected that the results will support Indonesia's defence technology independence and act as a design guide for the development of the next RX-70.

Research Methods

This study investigates how changes in star grain geometry and RDX content affect the propulsion performance of the RX-70 rocket motor using computer simulation methods. BurnSim software, a popular simulation tool for simulating the combustion properties and operation of solid-fuel rocket motors, was used to perform the simulations.

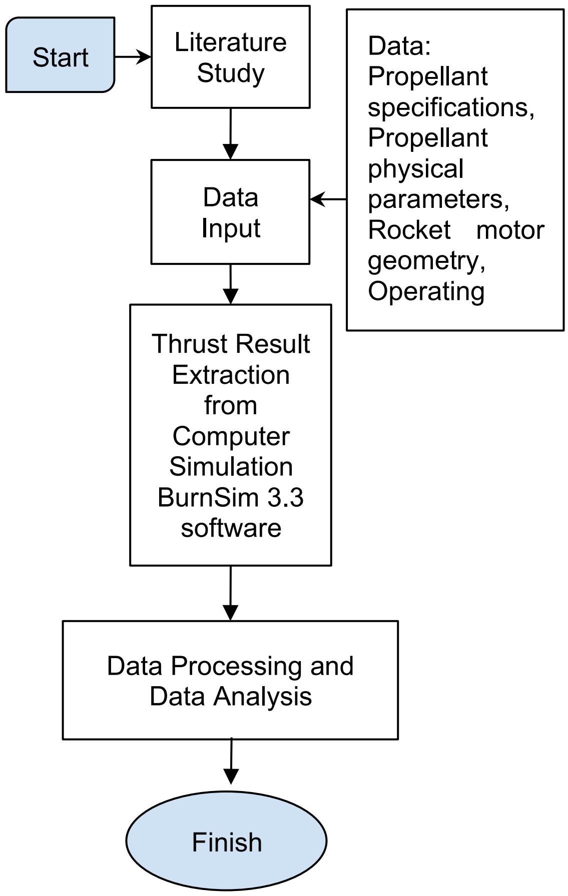


Figure 2. General Research Flowchart

Ammonium perchlorate (AP), aluminium (Al), hydroxyl-terminated polybutadiene (HTPB), and various amounts of RDX as active ingredients form the propellant composition. The mass composition data (wt%) of each propellant formulation are recorded based on research variations. The properties of the composite propellant are considered when adjusting the oxidizer particle size, propellant density, and related combustion parameters, including the initial burning rate (burning rate), pressure exponent, and combustion constant.

Table 1. Komposisi Bahan Bakar RDX 1%~20%

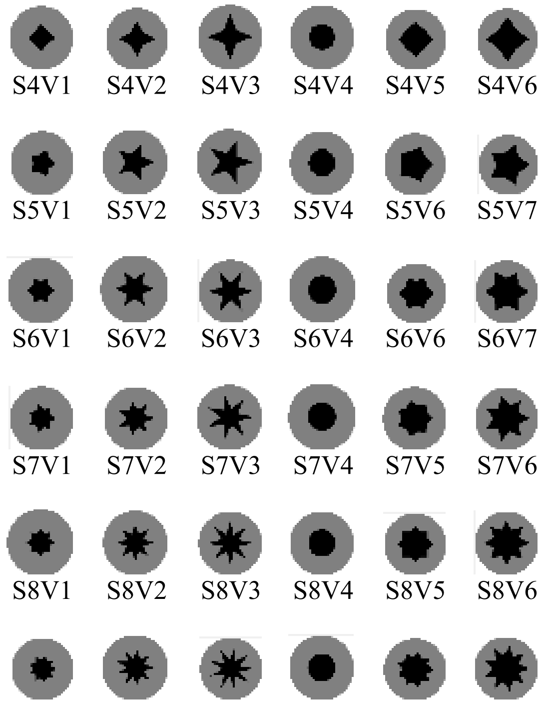
No.	Material	%
1.	Ammonium Perchlorate (AP)	76.5%~57.5%
2.	Alumunium (Al)	7.5
3.	Hydroxyl Terminated Polybutadiene (HTPB)	14
4.	Toluene Diisocyanate (TDI)	1
5.	Cyclotrimethylene Trinitramine (RDX)	1%~20%

The design parameters included are the RX-70 rocket motor model with modifications of the number of star beads (number of mould branches) and the main dimensions of the motor, such as tube diameter, bead length, and nozzle diameter. The effects of different star bead geometries on thrust and combustion chamber pressure are examined.

Table 2. Variasi Diameter Propelan

Variasi	Luar (mm)	Dalam (mm)
1	30	20
2	40	20
3	50	20
4	30	30
5	40	30
6	50	30

Table 3. Dimensi Variasi Propelan dan Jumlah Stars



#Star	Var. 1 30/20	Var. 2 40/20	Var. 3 50/20	Var. 4 30/30	Var. 5 40/30	Var. 6 50/30
4	S4V1	S4V2	S4V3	S4V4	S4V5	S4V6
5	S5V1	S5V2	S5V3	S5V4	S5V6	S5V7
6	S6V1	S6V2	S6V3	S6V4	S6V6	S6V7
7	S7V1	S7V2	S7V3	S7V4	S7V5	S7V6
8	S8V1	S8V2	S8V3	S8V4	S8V5	S8V6
9	S9V1	S9V2	S9V3	S9V4	S9V5	S9V6

After the simulation, 756 data points were generated under the assumption of 92% rocket motor efficiency using BurnSim. A filtered subset of 129 data points was then selected based on operational viability criteria: Burn Time between 1.5–3 (s), thrust between 1961,33–2206,5 N, and specific impulse above 210 seconds. These filtered data were used for more focused analysis.

Using a full factorial design to methodically assess the effects and interactions among several input components, the experimental and simulation setup adhered to Montgomery's Design of Experiments (DOE) technique [15]. This method guarantees a thorough statistical analysis and makes it possible to pinpoint important factors influencing system performance. Three-way ANOVA was used to evaluate the impact of critical parameters and statistically confirm the simulation results. The number of star points (6 levels), grain shape variance (6 types), and RDX content (21 levels: 0–20 wt%) were the independent variables. Thrust was the dependent variable. The entire data set (n = 756) and a filtered subset (n = 129) were subjected to analysis.

Table 4. Three-way ANOVA result of All Data

Dependent Variable	Factor	F-value	p-value (PR > F)	Sig.
Thrust	RDX	80.84	2.34E-142	Significant
	Var	14,839.91	0	Significant
	Star	52,852.52	0	Significant
	RDX:Var	1.83	1.44E-05	Significant
	RDX:Star	1.2	0.114	Not significant
	Var:Star	5,586.54	0	Significant
Burn Time	RDX	43.92	1.77E-96	Significant
	Var	454,713.45	0	Significant
	Star	663,850.42	0	Significant
	RDX:Var	1.16	0.16	Significant
	RDX:Star	1.53	0.0017	Significant
	Var:Star	57,361.96	0	Significant
Pressure	RDX	147.31	7.82E-195	Significant
	Var	891,520.87	0	Significant
	Star	199,525.34	0	Significant
	RDX:Var	4.54	6.73E-30	Significant
	RDX:Star	2.22	9.06E-09	Significant
	Var:Star	29,563.16	0	Significant
ISP	RDX	156.04	3.65E-200	Significant
	Var	1,630.95	7.35E-307	Significant
	Star	2,443.43	0	Significant
	RDX:Var	1.02	0.443	Not significant
	RDX:Star	0.76	0.951	Not significant
	Var:Star	290.54	2.88E-279	Significant

The complete statistical findings are presented in Table 4. Thrust, burn duration, pressure, and ISP were all significantly impacted by RDX, Var, and Star, according to a three-way ANOVA ($p < 0.001$). Interestingly, for every output, the Var × Star interaction remained substantial. RDX × Var interactions had a slight but statistically significant impact on thrust and pressure, but RDX × Star interactions were typically not significant. These findings demonstrate how design parameters affect propulsion performance both independently and in concert.

To assess the impact of RDX concentration, Star shape, and Var configuration on four critical performance parameters—thrust, burn time, chamber pressure, and specific impulse (ISP)—a three-way ANOVA was performed on the filtered data set, and the results are shown in Table 5. According to the analysis, thrust, burn time, and ISP are all statistically significantly affected by the three main factors—RDX, Var, and Star ($p < 0.05$). In some outputs, significant interaction effects are mostly seen in the

Var × Star combination, especially for thrust, burn time, and ISP. On the other hand, not all interactions are statistically significant for pressure, with only the main effects of Var and Star being significant. Interestingly, the RDX-related interactions (RDX × Var and RDX × Star) become significant for ISP but are generally insignificant for thrust, burn time, and pressure. According to these results, performance variation is significantly affected by Star and Var configurations, and propellant design should carefully consider their combined impacts. These findings lend credibility to the theory that star spots and nozzle shape—two geometry-driven grain features—play important roles in propulsion efficiency and combustion behavior.

Table 5. Three-way ANOVA result of filtered data

Dependent Variable	Factor	F-value	p-value (PR > F)	Sig.
Thrust	RDX	767.79	7.01E-05	Significant
	Var	36756.82	3.13E-07	Significant
	Star	28805.2	4.51E-07	Significant
	RDX:Var	0.15	999	Not significant
	RDX:Star	6.26	77	Not significant
	Var:Star	922.11	5.37E-05	Significant
Burn Time	RDX	468.44	1.46E-04	Significant
	Var	27662.1	4.79E-07	Significant
	Star	9389.39	2.02E-06	Significant
	RDX:Var	3.9	144	Not significant
	RDX:Star	5.43	93	Not significant
	Var:Star	660.86	8.85E-05	Significant
Pressure	RDX	1.29	467	Not significant
	Var	81.72	2.86E-03	Significant
	Star	14.1	30	Significant
	RDX:Var	1.17	529	Not significant
	RDX:Star	1.34	473	Not significant
	Var:Star	1.53	398	Not significant
ISP	RDX	9465.35	1.61E-06	Significant
	Var	561726.13	5.24E-09	Significant
	Star	192294.6	2.18E-08	Significant
	RDX:Var	47.62	42	Significant
	RDX:Star	68.26	24	Significant
	Var:Star	13280.76	9.85E-07	Significant

Results and Discussion

From 129 data combinations obtained through BurnSim simulation with 92% rocket motor efficiency, the next analysis discusses the variation of rocket motor performance based on the combination of major/minor width - star shape at each RDX composition from 0% to 20%. In this discussion, a comparison is made regarding the changes in burn time, thrust, pressure, and Isp for each RDX composition tested. The results of this analysis are divided into 10 parts covering the combination after optimization, as well as a comparison of performance between various configuration variations. The purpose of this discussion is to identify factors that significantly influence the optimization of rocket motor performance at each propellant variation.

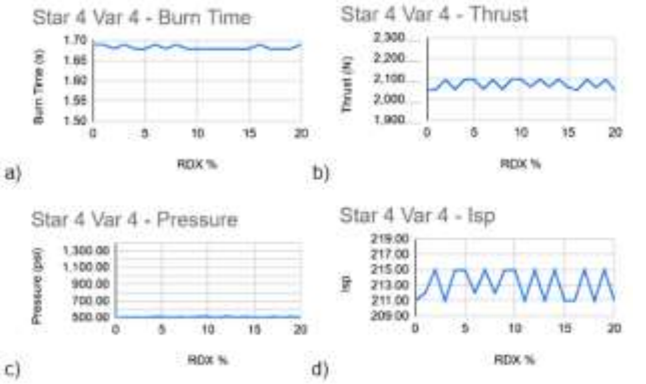


Figure 3. Graph of the Effect of RDX on a) Burn Time, b) Thrust, c) Pressure, d) Isp on the Star 4 Variation 4 (S4V4) combination

The data collected for S4V4 show the effect of RDX composition variation on key propellant performance parameters, including burn time, thrust, combustion chamber pressure, and specific impulse (Isp). The results show that the burn time is consistent between 1.68 and 1.69 s, indicating minimal variation in burn duration for different RDX levels. The thrust value slightly increases, ranging from 2,043.20 N to 2,098.81 N, where higher thrust is generally associated with increased combustion chamber pressure. The combustion chamber pressure itself varies between 502.50 psi and 518.90 psi, indicating a moderate increase with increasing RDX levels. In line with this, the specific impulse (Isp) is in the range of 211.00 s to 215.00 s, with an increasing trend as combustion chamber pressure and thrust increase, although in some conditions, the Isp value remains in the same range despite increasing RDX levels.

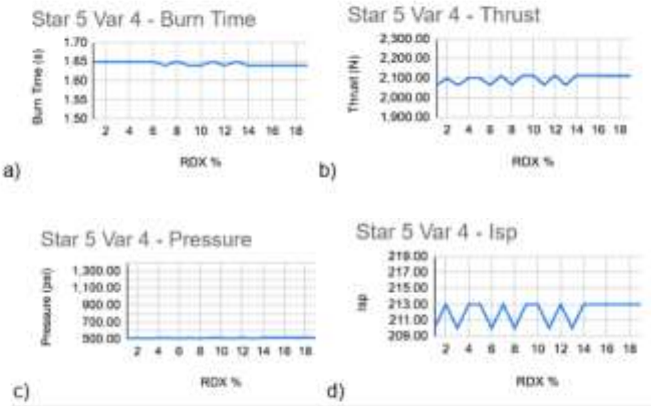


Figure 4. Graph of the Effect of RDX on a) Burn Time, b) Thrust, c) Pressure, d) Isp on the Star 5 Variation 4 (S5V4) combination.

In S5V4, the data shows a similar trend to S4V4, with some differences in key parameters such as burn time, thrust, combustion chamber pressure, and specific impulse (Isp). Burn time is slightly shorter than the previous configuration, ranging from 1.64 to 1.65 seconds, compared to 1.68 to 1.69 seconds in Star 4. This decrease indicates that increasing the number of stars can increase the burning surface area, which contributes to faster combustion. In terms of performance, thrust is slightly higher in S5V4, with a maximum value reaching 2,114.63 N, compared to 2,098.81 N in S4V4. Combustion chamber pressure also increased slightly, ranging from 506.10 to 519.70 psi, compared to 502.50 to 518.90 psi in Star 4. This increase is in line with the observed trend of increasing thrust. Meanwhile, the specific impulse (Isp) remained in the range of 210.00 to 213.00 s, indicating that despite the increase in pressure and thrust, the propellant efficiency in producing thrust per unit mass did not change significantly. This indicates that the Star 5 configuration is more optimal in increasing thrust, but does not provide significant advantages in combustion efficiency compared to Star 4.

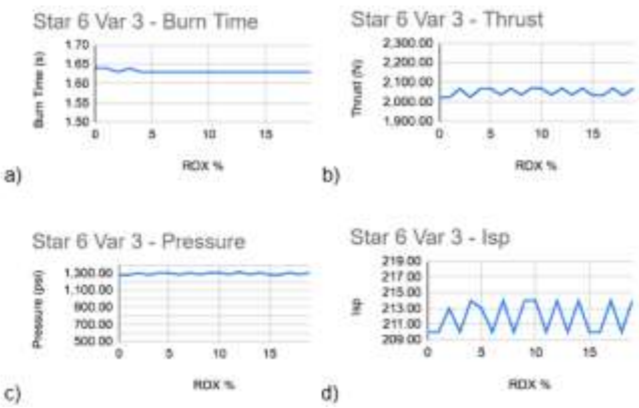


Figure 5. Graph of the Effect of RDX on a) Burn Time, b) Thrust, c) Pressure, d) Isp on the Star 6 Variation 3 (S6V3) combination

The S6V3 data results show significant differences compared to the previous configuration, S5V4, especially in terms of combustion chamber pressure. Burn time remains in a similar range to Star 5, which is 1.63 to 1.64 seconds, indicating that increasing the number of stars still results in a shorter burn duration compared to Star 4 (1.68–1.69 seconds). The most striking difference is seen in the combustion chamber pressure, which is in the range of 1,278.40 to 1,318.70 psi, much higher than 506.10 to 519.70 psi in Star 5. This increase in pressure is likely due to changes in grain geometry that increase the regression rate and burn rate of the propellant. Despite the increase in pressure, the maximum thrust only reached 2,070.55 N, which was not much different from 2,114.63 N in Star 5. Likewise, the specific impulse (Isp), which remained in the range of 210.00 to 214.00 s, showed that despite the drastic increase in combustion chamber pressure, the overall efficiency of the propellant in producing thrust did not change significantly. This indicates that increasing the number of stars does increase the combustion chamber pressure, but its impact on thrust and combustion efficiency is still limited.

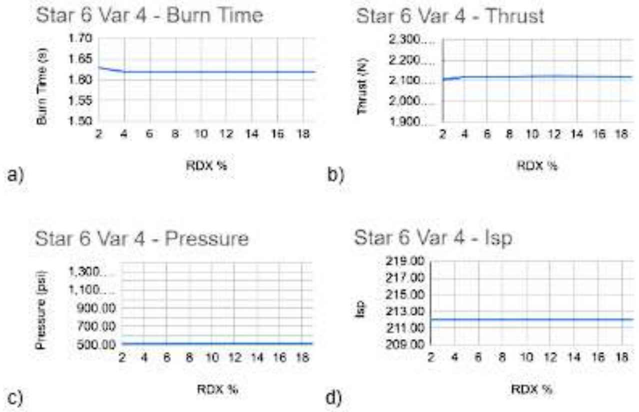


Figure 6. Graph of the Effect of RDX on a) Burn Time, b) Thrust, c) Pressure, d) Isp on the Star 6 Variation 4 (S6V4) combination

The S6V4 configuration shows improved performance compared to the S6V3, especially in terms of thrust and combustion chamber pressure. The combustion time has slightly accelerated, ranging from 1.62 to 1.63 seconds, compared to 1.63 to 1.64 seconds in the previous configuration. This difference indicates that changes in the star configuration can increase the rate of propellant combustion without sacrificing the stability of the combustion process. In terms of thrust, the maximum value achieved is 2,121.60 N, greater than 2,070.55 N in the S6V3. A significant difference is also seen in the combustion chamber pressure, where this configuration shows a range of 515.30 to 520.20 psi, much lower than the pressure reaching 1,278.40 to 1,318.70 psi in the previous variant. This decrease in pressure indicates better efficiency in propellant combustion, resulting in higher thrust with more controlled pressure. The specific impulse (Isp) remains at 212.00 s, indicating that the increase in thrust is not followed by a significant change in propellant efficiency. Thus, the S6V4 configuration is superior to the S6V3, as it is able to maintain combustion efficiency while producing greater thrust at lower pressures.

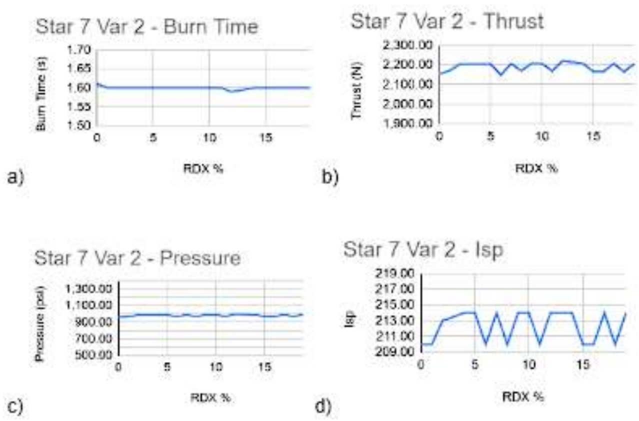


Figure 7. Graph of the Effect of RDX on a) Burn Time, b) Thrust, c) Pressure, d) Isp on the Star 7 Variation 2 (S7V2) combination

The S7V2 configuration shows significant performance improvements compared to the S6V4, especially in terms of combustion chamber pressure and thrust. The burn time has slightly accelerated, ranging from 1.59 to 1.61 seconds, faster than 1.62 to 1.63 seconds in the previous configuration, which is likely due to the increased burning surface area due to the greater number of stars. In terms of thrust, the highest value reaches 2,221.38 N, significantly increasing compared to 2,121.60 N in the S6V4, with the combustion chamber pressure also increasing from 515.30–520.20 psi to 966.70–995.90 psi. Despite the increase in thrust and pressure, the specific impulse (Isp) remains in the range of 210.00 to 214.00 s, indicating that the propellant efficiency has not changed significantly. Overall, increasing the number of stars in the grain geometry contributes to increased thrust and combustion chamber pressure, but it is still necessary to take into account the design implications for the casing material and the overall rocket motor system.

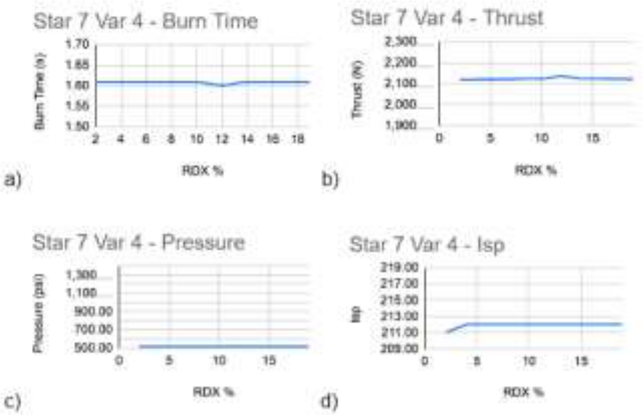


Figure 8. Graph of the Effect of RDX on a) Burn Time, b) Thrust, c) Pressure, d) Isp on the Star 7 Variation 4 (S7V4) combination

In the S7V4 configuration, propellant performance is affected by variations in RDX content, with trends showing a stable burn time of 1.60–1.61 seconds for all RDX percentages. At 2% RDX, the initial thrust was recorded at 2,119.25 N with a combustion chamber pressure of 515.70 psi and an Isp of 211.00 s. As the RDX content increased to 4–10%, the thrust increased slightly to 2,122.98 N, while the combustion chamber pressure increased to 517.90–518.00 psi, and the Isp remained at 212.00 s. At 12% RDX, there was a surge in thrust reaching 2,136.88 N, with the pressure increasing to 520.50 psi, but without significant changes in Isp. This trend shows that increasing RDX up to 12% contributed to the increase in pressure and thrust, but its effect on specific impulse remained minimal. Compared to S7V2, which at 12% RDX achieved a thrust of 2,221.38 N and a pressure of 995.90 psi, the main difference lies in the combustion energy distribution, where V4 has a lower pressure, indicating a more controlled combustion despite slightly lower thrust. This shows that higher RDX composition does not always increase propellant performance proportionally, especially if the grain geometry and pressure distribution in the combustion chamber are not optimal.

In the S7V5 configuration, the test results show that the combustion time remains constant at 1.61 seconds, without any significant variation due to changes in RDX content. At 7% RDX, the thrust was recorded at 2,090.06 N with a pressure of 709.40 psi and an Isp of 211.00 s. However, when the RDX content increased to 9–10%, the thrust actually decreased slightly to 1,961.49–1,962.11 N, while the combustion chamber pressure remained in the range of 710.20–710.30 psi. At 14% RDX, the thrust remained at 1,962.11 N, with a slight increase in pressure to 711.10 psi, with no change in the Isp value. Compared to the results on the S7V4, which showed a higher thrust at 2,122.98 N at 9% RDX, the V5 configuration actually produced lower thrust despite the higher pressure. Meanwhile, in S7V2, increasing RDX to 9% causes thrust to increase to 2,203.75 N with a pressure of 986.20 psi, showing a different pattern from V5, where higher pressure is not always directly proportional to the increase in thrust. This indicates that in the V5 configuration, the increase in combustion chamber pressure is not balanced with a more efficient energy release, so it does not produce a significant increase in thrust.

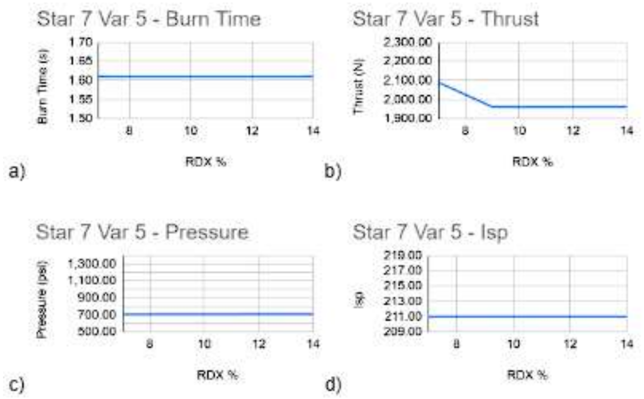


Figure 9. Graph of the Effect of RDX on a) Burn Time, b) Thrust, c) Pressure, d) Isp on the Star 7 Variation 5 (S7V5) combination

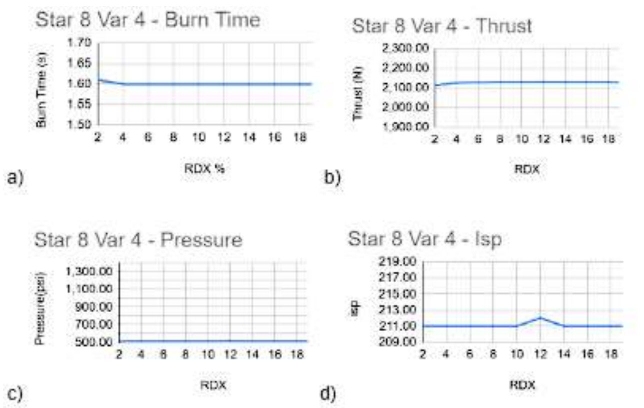


Figure 10. Graph of the Effect of RDX on a) Burn Time, b) Thrust, c) Pressure, d) Isp on the Star 8 Variation 4 (S8V4) combination

In the S8V4 configuration, the thrust value increases gradually along with the percentage of RDX, with a burning time that tends to be stable at 1.60–1.61 seconds. At 2% RDX, the thrust is recorded at 2,112.42 N with a pressure of 515.90 psi, while at 4–5% RDX, the thrust increases to 2,126.25–2,126.88 N with a pressure of 516.70–516.80 psi. A further increase to 9–10% RDX produces the highest thrust of 2,128.75 N, with a combustion chamber pressure reaching 518.10–518.20 psi. At 12% RDX, thrust increased slightly to 2,129.38 N, with a pressure of 520.80 psi and Isp increased to 212.00 s, while at 14–19% RDX, thrust tended to stagnate around 2,127.50–2,128.75 N, with stable combustion chamber pressure. Compared to S7V4, the S8V4 configuration showed a slight increase in thrust, especially at

9–10% RDX levels, where S7V4 only reached 2,122.98 N. However, when compared to S7V2, which was able to reach 2,203.75 N at 9% RDX, it can be seen that increasing the number of stars does not always result in a significant increase in thrust. In addition, when compared to S7V5, which experienced a thrust decrease at 9–14% RDX levels, the Star 8, Var 4 configuration showed more stable performance with a more consistent thrust increase pattern.

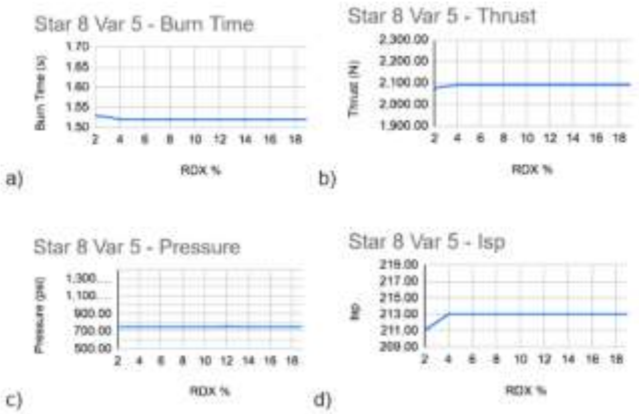


Figure 11. Graph of the Effect of RDX on a) Burn Time, b) Thrust, c) Pressure, d) Isp on the Star 8 Variation 5 (S8V5) combination

The S8V5 configuration shows a consistent thrust increase pattern with varying RDX content, although with higher combustion chamber pressure compared to the previous configuration. At 2% RDX, the initial thrust is at 2,075.82 N with a pressure of 747.20 psi. As the RDX content increases to 4–5%, the thrust increases slightly to 2,090.13–2,090.79 N, while the pressure increases to 748.10–748.20 psi. At 7–10% RDX, the thrust reaches 2,092.11–2,092.76 N, with a stable pressure in the range of 749.00–749.90 psi. Further increases to 12–19% RDX show that the thrust remains around 2,092.76 N, with a maximum pressure reaching 753.60 psi before dropping slightly to the range of 750.70–750.90 psi. Compared to the S8V4, this configuration shows higher combustion chamber pressure (747.20–750.90 psi compared to 515.90–519.10 psi), while the thrust value only increases slightly. According to Kamran et al.'s study [16], an 8-star grain configuration produced a stronger specific impulse (ISP) than a 7-star configuration. This result is consistent with that study. The comparative rise from 7 to 8 stars is noticeable, even if their investigation showed that ISP improvement plateaus beyond 8 stars. This confirms the S8V5 configuration's reported performance and highlights how well the S8v5 enhances ISP in comparison to the S7V5. This confirms the S8V5 configuration's performance and highlights the 8-star design's potential to maximize ISP efficiency. The result also indicates that the V5 configuration produces more intense combustion performance with higher pressure. Compared to the S7V2, the thrust on the S8V5 is more stable, although it does not reach the peak value of 2,221.38 N seen in the S7V2 at 12% RDX. Compared to the S7V5, this configuration has higher and more consistent thrust, indicating that the use of the Star 8 geometry provides better stability in the combustion process, especially at higher RDX levels.

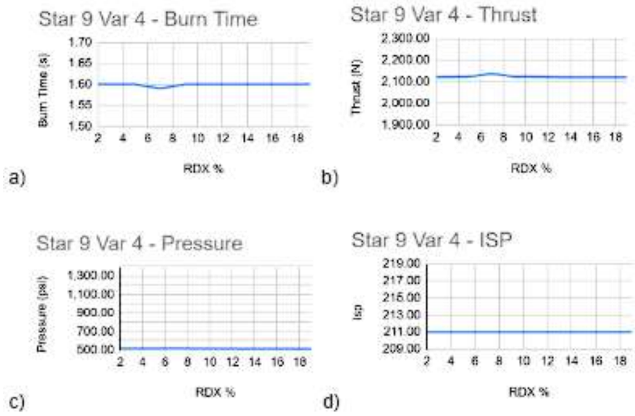


Figure 12. Graph of the Effect of RDX on a) Burn Time, b) Thrust, c) Pressure, d) Isp on the Star 9 Variation 4 (S9V4) combination

The S9V4 configuration shows thrust stability with relatively small fluctuations compared to the previous configuration. At 2% RDX, the thrust was recorded at 2,122.50 N with a pressure of 519.30 psi, while at 4–5% RDX, the thrust increased slightly to 2,123.75 N with a pressure that remained around 519.10–519.20 psi. A significant increase was seen at 7% RDX, where the thrust increased to 2,137.74 N, although the pressure only increased to 521.00 psi. However, after that, the thrust fell back to near the initial value, with the pressure tending to decrease from 518.40 psi at 9% RDX to 516.10 psi at 19% RDX. Compared to S8V4, this configuration has slightly higher thrust at some RDX levels, but does not show a significant increase at higher levels, which is different from the pattern in S8V4, where thrust tends to be more stable at higher RDX levels. When compared to S7V4, this configuration maintains a more consistent thrust, with lower peak values compared to the thrust spikes that occurred in Star 7. Overall, the Star 9 geometry in Var 4 appears to provide better thrust stability but does not provide a significant increase in performance compared to the previous geometry. Analysis of various Star 4 to Star 9 configurations with varying RDX percentages shows that changes in grain geometry have a more dominant effect on burn time, thrust, pressure, and Isp compared to variations in RDX levels in the range tested. Configurations with higher star counts, such as Star 7, 8, and 9, tend to produce more stable thrust with higher combustion chamber pressures, although the increase is not always linear with RDX percentage. For example, Star 7 Variation 2 experienced a significant increase in thrust compared to other variations with RDX content of 7–12%, while Star 8 Variation 5 showed the highest combustion chamber pressure, reaching 750–753 psi with stable thrust above 2,090 N. However, Star 9 Variation 4, despite having thrust stability, did not show a significant increase compared to Star 8 Variation 4, indicating that geometry optimization is not always directly proportional to increased rocket motor performance. Compared to the Star 4 to Star 6 configurations, the configurations with a lower number of stars showed a more fluctuating thrust pattern and a tendency for lower combustion chamber pressure. For example, in Star 6 Variation 4, the combustion chamber pressure was in the range of 515–520 psi with relatively stagnant thrust, while Star 5 Variation 4 showed similar results with small differences in burn time and specific impulse. In general, the Star 7 to Star 9 configurations with higher RDX content variations provided more stable performance in thrust and pressure, especially at RDX content above 7%. However, the configuration with lower stars is more sensitive to composition changes. This suggests that increasing the number of stars can help optimize pressure distribution and combustion in the combustion chamber, but its effect on thrust enhancement requires further study to determine the optimum point.

Variants with fewer stars exhibit more erratic thrust patterns and typically have lower combustion chamber pressures than the 4-Star to 6-Star variants. For example, the 5-Star Variation 4 has comparable results with small variations in burn time and specific impulse, while the 6-Star Variation 4 has a combustion chamber pressure in the range of 515–520 psi with very static thrust. Thrust and pressure performance are generally more stable in the 7-Star to 9-Star designs with larger changes in RDX content, especially at RDX contents above 7%. On the other hand, the lower star configurations are more susceptible to compositional changes. This implies that adding more stars can improve combustion and pressure distribution in the combustion chamber, but further research is needed to find the ideal balance in terms of thrust enhancement. Further investigation revealed that, within the range of variations used in this study, changes in RDX% % had no discernible impact on thrust, Isp, or burn duration. The overall trend shows that the variation in thrust and combustion chamber pressure is driven more by the grain geometry configuration than by the RDX concentration, although there is little variation between the variations. In contrast to other variants with varying RDX contents, Star 8 Variation 5, which has the highest combustion chamber pressure (753 psi) and a stable thrust above 2,090 N, does not show a sharp spike. In the same vein, Star 7 Variation 5 maintains Isp between 211 and 213 s despite a decrease in thrust to 1,961 N. This suggests that the variations in RDX content have a smaller impact on performance than they do on increasing propellant performance. Instead, they are more important for maintaining combustion chamber pressure stability. With stable thrust, the highest combustion chamber pressure of 753 psi, and superior specific impulse compared to the previous variants, Star 8 Variation 5 shows the best overall performance analysis. The improved combustion efficiency is demonstrated by the ability of this configuration to maintain thrust above 2,090 N at higher pressures than Stars 7 and 9. Star 8 Variation 5 is better at maintaining constant pressure and thrust at different %RDX than Star 7 Variation 5, which experiences a thrust drop to 1,961 N, and Star 9 Variation 4, which has a lower combustion chamber pressure (516–521 psi). As a result, this arrangement can be considered an ideal option for propellant design optimization to improve the performance of the RX-70 rocket motor.

Although the simulation findings provide valuable information on how RDX content and grain geometry affect performance, the research is based only on BurnSim computational results. Complex combustion dynamics including heat losses, structural deterioration, and real-time thermal feedback are not taken into consideration by the simulation. Furthermore, it is difficult to completely validate the anticipated results due to the lack of experimental fire experiments. Therefore, even while the trends found—like the 8-star, Variation 5 configuration's performance advantages—are encouraging, they should be regarded as preliminary until they are confirmed by experimental testing.

Conclusion

Investigation of several 4- to 9-star designs revealed that varying RDX concentration over the observed range had a smaller impact on burn time, thrust, combustion chamber pressure, and specific impulse (Isp) than grain shape. The 7- to 9-star arrangement had better thrust stability and produced higher combustion chamber pressures than the 4- to 6-star system. With a peak combustion chamber pressure of 753 psi and a stable thrust above 2,090 N, the 8-star configuration with Variation 5 performed the best among all, indicating maximum combustion efficiency. In addition to the increased burning surface area, this performance improvement could also be the result of internal geometry modifications that affect the distribution (grammage) of the composite propellant components. Variations in grammage caused by grain shape could affect local combustion behavior and result in more effective energy release during combustion. These results provide valuable design information for optimizing solid rocket motors, especially in engineering and instructional contexts. Early-stage design assessments or rocket propulsion courses can use the data-driven discovery of ideal grain geometry as a guide. Additionally, prior to extensive testing, the use of simulation-based techniques such as BurnSim offers an affordable learning tool for examining interior ballistics.

Author's Contribution

Muhammad Ichsanul Adzan: melakukan simulasi BurnSim, analisis data. Yayat Ruyat: membantu menafsirkan hasil kinerja pembakaran. Heri Budi Wibowo: memberikan keahlian dalam formulasi propelan dan memvalidasi hasil simulasi.

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