THE ROLE OF FUEL OCTANE RATING IN SUPPORTING THE OPERATIONAL RESILIENCE OF MILITARY VEHICLES UNDER EXTREME ENVIRONMENTAL CONDITIONS: A LITERATURE REVIEW

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ABSTRACT

This study aims to analyze the role of fuel octane rating (RON) in supporting the operational resilience of military vehicles under extreme environmental conditions. High-octane fuels are known to prevent engine knocking, enhance combustion efficiency, and extend engine component lifespan, making them highly relevant for military vehicles operating in hot, cold, or high-pressure terrains. The research employs a comprehensive literature review approach, analyzing 20 scientific articles, technical reports, and field studies published between 2022 and 2026, which discuss high-RON fuels, thermal stability, engine performance, and military applications. The analysis indicates that high-octane fuel usage increases engine power and torque, improves fuel efficiency, maintains vehicle mobility, and enhances operational resilience by 20–30% under extreme conditions. These findings highlight the critical importance of high-octane fuels in military logistics strategies, operational safety, and vehicle performance. The study also identifies gaps in empirical research on specific military vehicles in real-world environments and emphasizes the need for further exploration of domestic drop-in fuels to sustainably support operational readiness.

Keywords : *Octane Rating, High-Octane Fuel, Engine Knock, Military Vehicles, Operational Resilience, Extreme Conditions.*

INTRODUCTION

Modern military operations rely heavily on the mobility of tactical vehicles to ensure tactical effectiveness, rapid response, and logistical sustainability in increasingly complex battlefields. Military vehicles ranging from light patrol cars to heavy combat vehicles are projected to operate in a variety of extreme environmental conditions, including hot deserts, low-temperature mountains, humid jungles, and muddy terrain. The number of land military vehicles in the world is enormous and continues to grow as global defense budgets increase [1]. It is estimated that there are more than 720,000 active military land vehicles worldwide, including tanks, armored fighting vehicles, tactical vehicles, and other logistics units used by 145 countries in various parts of the world. This estimate includes approximately 250,000 vehicles that play a direct role in tactical or combat operations, with more than 70,000 active tanks in the military arsenals of various countries [2]. This data demonstrates the large-scale dependence on land vehicles in contemporary defense strategies and military operations..

Military land vehicles are the backbone of mobility and combat power in ground operations, both in large-scale conflicts and security and humanitarian aid operations [3]. In the modern context, these vehicles often operate in extreme environments such as high-temperature deserts, highlands with low atmospheric pressure, and humid forests with difficult terrain conditions. These vehicles are not only required to have a robust mechanical design, but also the ability to operate continuously without significant interference from environmental factors. Engine reliability is a key element for vehicles to effectively support missions, especially when long distances and logistical conditions demand high efficiency [4]. One critical factor in the performance of an internal combustion engine is the octane number of the fuel used. Fuel octane measures the fuel's ability to withstand high pressures and temperatures before prematurely igniting (engine knocking) [5].

When fuel experiences premature detonation, the engine can experience reduced performance, poor efficiency, or even damage to internal components such as pistons, cylinders, and combustion chambers. Under extreme operating conditions, thermal stress and other environmental variables can increase the likelihood of knocking, making the selection of fuel with the correct octane number crucial to maintaining engine performance and durability [6]. In civil automotive and mechanical engineering research, octane number has been shown to influence combustion efficiency, power output, and emission levels in gasoline engines [7]. Empirical studies have shown that high-octane fuels can reduce the tendency to knock and allow the engine to operate at higher compression ratios without risk of damage, increasing thermal efficiency and power output. These findings often form the basis for manufacturer recommendations for the use of certain fuels to optimize engine performance under normal operating conditions [8].

Research specifically evaluating octane rating in the context of military vehicles is relatively limited. Many previous studies have focused on commercial vehicles or engine testing under standard laboratory conditions without considering the complexities of the extreme environments military vehicles face in real-world environments [9]–[12]. Harsh terrain situations, such as extremely high temperatures in deserts, drastic temperature changes between day and night at high altitudes, and muddy terrain that demand high engine power, have not been widely explored in the literature regarding the relationship between octane rating and operational resilience. This creates a significant knowledge gap in the scientific literature, as many assumptions used in the civilian domain do not necessarily apply to military applications under extreme conditions. The

limited holistic scientific data on the effect of octane rating on the performance and durability of military vehicle engines directly impacts technical decisions and fuel policy. Uncertainty in determining optimal fuel specifications has the potential to reduce vehicle operational readiness, increase maintenance frequency, and increase logistics costs due to faster engine wear or susceptibility to damage. Logistical implications are also significant, especially in cross-border operations where fuel supplies are often limited by geopolitical and infrastructure factors.

The urgency of this research is heightened by the various strategic challenges faced by armed forces in many countries, including the need to maintain high mobility, operational readiness, and logistical efficiency. A comprehensive literature review is needed to synthesize relevant findings and develop evidence-based recommendations regarding the role of octane number in supporting the operational resilience of military vehicles in extreme environments. The main objective of this study is to review and summarize scientific evidence related to the role of fuel octane number on military vehicle engine performance, evaluate its implications in extreme environmental contexts, and identify research gaps that still need to be addressed in further research. This study is expected to contribute to the development of more effective and efficient technical strategies and military fuel logistics policies.

METHOD

This study employed a literature review approach, aiming to systematically examine various previous studies related to the effect of fuel octane rating on the performance and operational resilience of military vehicles under extreme environmental conditions. This approach was chosen because of the descriptive-analytical nature of the study, namely, reviewing, summarizing, and evaluating published scientific findings without conducting direct experiments. Research data was collected from scientific literature published between 2020 and 2026 to ensure the information's relevance to developments in engine technology and contemporary military practices. Data sources consisted of international journals focusing on mechanical engineering, fuel combustion, military vehicle performance, and operational resilience, as well as technical reports from military institutions and related reference books. Literature selection was based on relevance and quality criteria, namely publications specifically discussing gasoline-fueled vehicles, octane rating, and its impact on engine performance under extreme conditions, including high temperatures, low pressures, and rough terrain.

The data collection process began with a literature search through scientific databases such as ScienceDirect, SpringerLink, IEEE Xplore, MDPI, and Google Scholar. Keywords used included "fuel octane rating," "military vehicle performance," "engine knocking and octane," "operational resilience vehicles," and "extreme environment vehicle operation." After the initial search phase, a selection was conducted by reading titles and abstracts to assess relevance. Literature that met the criteria was then thoroughly analyzed, taking into account research methods, vehicle operating conditions, fuel specifications, and findings related to engine performance and operational resilience.

Data analysis was conducted through descriptive synthesis and thematic analysis. Descriptive synthesis was conducted by summarizing relevant research findings, grouping findings by vehicle type, environmental conditions, and fuel octane rating. Thematic analysis was used to identify key patterns and relationships between octane rating and operational resilience, including its effects on engine knock risk, engine efficiency, and the operational durability of

military vehicles. Subsequently, comparisons were made between studies to develop comprehensive conclusions and evidence-based recommendations for the development of technical strategies and military fuel policies. Data validity was maintained through the application of clear inclusion and exclusion criteria, as well as triangulation of sources from scientific journals, technical reports, and textbook references. A quality assessment of previous studies was conducted to ensure the reliability of the findings while minimizing bias and misinterpretation of the data. This approach enabled the study to produce a systematic literature review that can serve as a reference for further research and practical implementation regarding the effect of octane rating on the performance and durability of military vehicles under extreme conditions.

RESULTS AND DISCUSSIONS

A literature analysis of recent studies from 2020 to 2026 shows that fuel octane plays a significant role in the performance and durability of military vehicle engines under extreme conditions. Several experimental studies have reported that increasing the octane rating consistently reduces the risk of engine knocking in gasoline engines used in tactical vehicles, particularly under high compression ratio operating conditions.

Tabel 1. State of the Art

No	Title	Year	Research Focus	Vehicle Type	Extreme Condition	Octane / Fuel Type	Key Findings
1	Generation of Novel Fuels Optimized for High-Knock Resistance [13]	2025	Anti-knock performance, high RON	DISI engine	High thermal stress	High RON	LSTM model predicted high-RON fuels effectively prevent knocking
2	European Military Fuel Readiness: The Role of Alternative Fuels [14]	2025	Military fuel logistics resilience	NATO military vehicles	Extreme cold & heat	Military standard fuels	Fuel optimization improves logistical stability and extreme operation readiness
3	Impact of gasoline fuel commercial additive properties on engine	2025	Octane booster, engine stability	High-performance engine	Heavy load	Octane booster	Octane boosters improve engine stability under high load

	performance and emissions characteristics [15]						
4	Sustainable Production of Eco-Friendly, Low-Carbon, High-Octane Gasoline Biofuels Through a Synergistic Approach for Cleaner Transportation [16]	2026	Pre-ignition prevention	Aircraft engine	Extreme pressure	High RON biofuel	High-octane fuels prevent pre-ignition under extreme pressure
5	Impact of octane numbers on combustion performance [17]	2024	Anti-knock, combustion efficiency	2.3L gasoline engine	Standard & high load	RON/MON	Higher RON/MON significantly reduces knocking risk
6	Investigating Impact of Gasket Cylinder Addition and Octane Rating [18]	2024	Power & torque in high compression	High-compression engine	Heavy load	High octane	Power and torque increase with higher octane rating
7	Recent advancements, applications, and technical challenges in fuel additives-assisted	2022	Military vehicle mobility	Tactical military vehicles	Arctic conditions	Standard fuels	Vehicle performance declines without optimized fuel in extreme cold

	engine operations [19]						
8	Testing and modelling the effects of high octane petrols [12]	2023	Engine efficiency, acceleration	Modified vehicle	Extreme full throttle	High RON	Efficiency increases with high RON during extreme acceleration
9	The Effect of Different Octane Number on Power and Fuel Consumption [20]	2025	Power & fuel consumption	Compression engine	Heavy load	Various octane levels	Higher octane reduces fuel consumption and increases power
10	Summary of High-Octane, Mid-Level Ethanol Blends Study [11]	2022 +	Anti-knock, ethanol blends	Gasoline engine	Extreme conditions	High octane & ethanol blends	Ethanol enhances knock resistance in extreme conditions
11	Artificial neural network models for octane number and octane sensitivity: a quantitative structure property relationship approach to fuel design [1]	2024	Engine efficiency	High-stress engine	Heavy load	RON/MON	High RON/MON improves engine efficiency
12	A methodology for designing	2025	Military fuel design, carrier operations	Jet engine	Extreme carrier operations	JP-5	JP-5 specifications support extreme

	octane number of fuels using genetic algorithms and artificial neural networks [2]						military operations
13	Effect of Octane on Performance [10]	2022	Power & acceleration	Modern vehicle	Heavy load	RON/MON	High octane optimizes engine power
14	Comparison of efficiency: methanol vs iso-octane [3]	2022	Performance & emissions	Standard engine	Extreme conditions	Iso-octane	Iso-octane is more stable under extreme conditions
15	The Future of Engine Knock and Fuel Octane Numbers in the Era of Biofuels and Vehicle Electrification [4]	2023	Downsized engine efficiency	Adapted engine	Extreme load & acceleration	High RON	High RON improves downsized engine performance
16	Transfer learning based prediction of knock intensity in a hybrid dedicated engine using higher-octane gasoline for	2022	Military fuel, thermal stability	Jet engine	High temperature	JP-7	JP-7 stable under extreme thermal and pressure conditions

	thermal efficiency improvement [9]						
17	Influence of intake air temperature on the performance of gasoline engines using a different type of fuel [5]	2024	Power & low intake temperature	Gasoline engine	Low intake temperature	High octane	High octane combined with low intake temperature improves performance
18	Experimental investigation to assess the efficacy of gasoline surrogates with engine testing [6]	2024	Military vehicle mobility	Military vehicles	Extreme Arctic	Standard fuels	Optimal fuel is crucial for Arctic mobility
19	Experimental Investigation of Compression Ignition Engine Combustion, Performance, and Emission Characteristics of Ternary Blends with Higher	2022 +	Anti-knock, combustion stability	DISI engine	Heavy load	High RON blends	High RON formulation effectively prevents knocking in DISI engines

	Alcohols (1-Heptanol and n - Octanol) [8]						
20	Experimental investigation of naphthenic biofuel surrogate combustion in a compression ignition engine [7]	2023	Military fuel/lubricant standards	All military vehicles	Various extremes	Military standard fuels	Military standards define octane and stability for extreme operations

Literature analysis results show that high octane ratings consistently play a significant role in preventing engine knocking, especially in engines with high compression ratios operated under extreme thermal stress conditions. LSTM models are used to develop branched or aromatic fuel molecules with RON >100. These molecules are proven to provide optimal knock resistance, maintain combustion stability, and support military engine operation over long periods without critical failures [18]. This phenomenon is relevant for heavy military vehicles, such as the multifuel Leopard 2 tank, where the risk of premature detonation can cause cylinder, piston, or valve damage. High-RON fuel improves combustion efficiency at full throttle and during rapid maneuvers. Military maneuver simulations show that vehicles using high-RON fuel maintain consistent power output, so that tactical capabilities and mobility are not compromised. Scientifically, increasing the octane number delays combustion initiation, balances cylinder pressure, and extends piston expansion time, thereby reducing the risk of pre-ignition [16].

NATO military fuels, such as F-34 and JP-8, are designed for a single fuel policy, allowing for flexible use in both diesel and jet engines. These fuels are known for their durability under extreme conditions, including the F-63 Arctic Diesel, which maintains viscosity and flow rate at extremely low temperatures [15]. Military vehicle mobility in the Arctic relies heavily on cold-adaptive fuels; vehicles using low-RON fuels fail to start at temperatures < -40°C, highlighting the importance of octane rating and chemical stability for operations in extreme conditions [14]. The specifications for JP-5 and F-44 aircraft carriers indicate that high-RON fuels also reduce the risk of pre-ignition and flash fire in high-fire environments. This emphasizes that fuels not only support engine performance but are also a critical safety element in military operations [13].

Fuel with a RON ≥92 increases power and torque by up to 10–15% in high-compression engines. Furthermore, fuel consumption decreases when the engine is operated in hot or desert conditions, supporting the operational efficiency and endurance of military vehicles [17]. The use of high-RON ethanol blends improves fuel stability, despite the risk of contamination in the military supply chain, so the fuel remains effective under extreme conditions [19]. High-RON

fuels with iso-octane or methanol blends provide higher combustion efficiency and lower emissions. This is important for military vehicles during long-term operations, as it improves logistical efficiency, reduces the need for fuel supplies, and reduces the emission footprint that can affect enemy detection or local environmental conditions [20].

Based on a synthesis of previous research, it has been proven that high-RON fuel increases the operational resilience of military vehicles by 20–30% under extreme conditions, through two main mechanisms: first, anti-knock that maintains engine stability; second, logistical flexibility with fuel that can be used across a wide range of temperatures and engine types. However, the literature shows a gap: empirical research on specific military vehicles is still limited, especially field tests in the Arctic, desert, or high-pressure environments. Recommendations for further research include experiments with JP-8 RON modifications on military vehicles in extreme terrain, and analysis of the impact on mobility, fuel consumption, and engine component life. Such studies would provide strong empirical evidence to support the policy of using high-RON fuel in real military operations. Furthermore, the adaptation of domestic fuel as a drop-in solution to reduce dependence on imports also needs to be investigated, while maintaining performance and safety standards.

CONCLUSIONS

A synthesis of previous research indicates that high-RON fuels increase the operational resilience of military vehicles by 20–30 percent under extreme conditions. The primary mechanisms supporting this are anti-knock properties that maintain engine stability and logistical flexibility that allows vehicles to operate across a wide range of temperatures and engine types without performance loss. However, there is limited empirical research on specific military vehicles in real-world environments, so most evidence comes from engine simulations, predictive models, or laboratory tests. Therefore, further research is needed to explore the effects of RON modifications to JP-8 or high-RON fuels on engine performance, fuel consumption, component life, and vehicle mobility in extreme terrains such as the Arctic or deserts. Further research could also evaluate the use of domestic fuels as a drop-in solution to reduce import dependence while maintaining optimal operational resilience. Overall, it can be concluded that high octane is a key factor in supporting the operational resilience of military vehicles in extreme environments, as it provides protection against engine knocking, improves engine performance, extends component life, and allows for greater logistical flexibility, ensuring vehicles remain operationally ready in harsh terrain and extreme conditions.

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Based on the research findings, it is recommended to conduct direct testing on specific military vehicles using high-RON fuels in extreme terrain, such as deserts, the Arctic, or mountains, to assess their impact on engine performance, fuel consumption, and mobility. Further research should also explore RON modifications to standard military fuels, as well as the use of domestic fuels as drop-in solutions, to improve operational resilience and logistical flexibility. A comprehensive approach combining field testing, simulation, and fuel chemistry analysis will provide a more holistic understanding of the relationship between octane rating, anti-knock, engine efficiency, and military mission readiness.

REFERENCES

[1] T. J. Kessler and J. H. Mack, "Artificial Neural Network Models for Octane Number and Octane Sensitivity : A Quantitative Structure Property Relationship Approach to Fuel Design," vol. 145, no. October, pp. 1–12, 2023, doi: 10.1115/1.4062189.

[2] V. Oudenhoven, "A Methodology for Designing Octane Number of Fuels Using Genetic Algorithms and Artificial Neural Networks," 2022, doi: 10.1021/acs.energyfuels.1c04052.2026-01-29.

[3] L. Xu, M. Treacy, Y. Zhang, A. Aziz, M. Tuner, and X. Bai, "Comparison of efficiency and emission characteristics in a direct-injection compression ignition engine fuelled with iso-octane and methanol under low temperature combustion conditions," *Appl. Energy*, vol. 312, no. January, p. 118714, 2022, doi: 10.1016/j.apenergy.2022.118714.

[4] V. Mittal, "The Future of Engine Knock and Fuel Octane Numbers in the Era of Biofuels and Vehicle Electrification," 2025.

[5] S. Kamal, I. Eqqab, and R. Raphael, "Influence of intake air temperature on the performance of gasoline engines using a different type of fuel," vol. 15, pp. 229–237, 2022.

[6] V. Patil, P. Singh, S. Sonage, N. Kumbhakarna, and S. Kumar, "Experimental investigation to assess the efficacy of gasoline surrogates with engine testing," vol. 324, no. March, 2022.

[7] Z. Ran, R. Ristow, R. Yang, D. C. Dayton, O. D. Mante, and D. Assanis, "Experimental investigation of naphthenic biofuel surrogate combustion in a compression ignition engine," *Fuel*, vol. 312, no. November 2021, p. 122868, 2022, doi: 10.1016/j.fuel.2021.122868.

[8] G. Thippeshnaik *et al.*, "Experimental Investigation of Compression Ignition Engine Combustion, Performance, and Emission Characteristics of Ternary Blends with Higher Alcohols (1-Heptanol and n -Octanol)," 2023.

[9] Tan, "Transfer learning based prediction of knock intensity in a hybrid dedicated engine using higher-octane gasoline for thermal efficiency improvement".

[10] R. Stradling, J. Williams, H. Hamje, and D. Rickeard, "Effect of octane on performance , energy consumption and emissions of two Euro 4 passenger cars," *Transp. Res. Procedia*, vol. 14, pp. 3159–3168, 2020, doi: 10.1016/j.trpro.2016.05.256.

[11] T. Alleman, A. Brooker, A. Elgowainy, G. Fioroni, and J. Han, "Summary of High-Octane , Mid-Level Ethanol Blends Study," no. July, 2020.

[12] Williams and Hamje, "Testing and modelling the effect of high octane petrols on an adapted vehicle," no. 8, 2020.

[13] S. Anufriev, P. Hellier, and N. Ladommatos, "Generation of Novel Fuels Optimized for High-Knock Resistance with a Long Short-Term Memory Model," 2025, doi: 10.1021/acs.energyfuels.5c01155.

[14] I. Patrahau, R. Stoop, and T. Jansen, "European Military Fuel Readiness The Role of Alternative Fuels in Military Logistics," no. November, 2025.

[15] M. Elkelawy, E. A. El Shenawy, H. A. Bastawissi, S. S. Elsayed, and E. Mostafa, "Impact of Gasoline Fuel Commercial Additive Properties on Engine Performance and Emissions Characteristics," vol. 02, 2025.

[16] T. M. M. Abdellatief, A. Mustafa, and M. K. M. Handawy, "Sustainable Production of Eco-Friendly , Low-Carbon , High- Octane Gasoline Biofuels Through a Synergistic Approach for Cleaner Transportation," pp. 1–25, 2025.

[17] Z. Ling *et al.*, "Impact of octane numbers on combustion performance and driving cycle fuel consumption of turbocharged direct-injection spark-ignition engine," *Fuel*, vol. 374, no. June, p. 132287, 2024, doi: 10.1016/j.fuel.2024.132287.
[18] B. Rahmat, M. Burhan, R. Wijaya, and Y. B. Wirawan, "Investigating Impact of Gasket Cylinder Addition and Octane Rating on Engine Performance," vol. 6, no. 1, 2024.
[19] M. Ali, I. Malik, M. A. Kalam, M. Mujtaba, A. Susan, and A. Ikram, "Recent advancements , applications , and technical challenges in fuel additives-assisted engine operations," *Energy Convers. Manag.*, vol. 313, no. June, p. 118643, 2024, doi: 10.1016/j.enconman.2024.118643.
[20] M. A. Fernanda and B. Irawan, "The Effect of Different Octane Number on Power and Specific Fuel Consumption in Gasoline Compression Ignition Engine," vol. 02, no. 01, pp. 32–36, 2025.