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ANALYSIS OF YAMAHA NMAX MOTORCYCLE PERFORMANCE WITH VARIATIONS IN PISTON DIAMETER AND FUEL TYPE

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ABSTRACT

Small-displacement motorcycles like the Yamaha NMAX are commonly modified with bore-up piston kits and higher-octane fuel, yet the interaction between these modifications remains empirically unexamined. This study evaluated the effects of piston diameter variation and fuel octane rating on NMAX engine performance by comparing a standard 58 mm piston against a 4 mm oversize piston paired with Pertalite (RON 90) and Pertamax Plus (RON 95) fuel. Dynamometer testing across 2000–9000 RPM measured torque, power, and fuel consumption, complemented by qualitative observation of knock behavior and thermal dynamics. Results showed the oversize piston increased peak torque by 15–18% and power by 12–16%, with 8–12% higher fuel consumption. Critically, a synergistic effect emerged: Pertamax Plus provided only 3–5% power gain with standard pistons but substantial additional improvements with the oversize piston while reducing fuel consumption penalty from 8.6% to 6.1%. Knock onset shifted from 6800 RPM (oversize + Pertalite) to 7200 RPM (oversize + Pertamax Plus). These findings demonstrate that mechanical and chemical modifications function as complementary variables requiring concurrent optimization. The research provides evidence-based recommendations for balancing performance, efficiency, and reliability.

Keywords : *motorcycle engine performance, bore-up modification, fuel octane rating, engine knock, fuel consumption*

1. Introduction

Urban commuters routinely modify the Yamaha NMAX 155 cc engine through bore-up piston installation and higher-octane fuel selection in pursuit of improved acceleration and power delivery [1]. However, these modifications are typically implemented independently based on anecdotal guidance rather than systematic empirical evaluation. The NMAX, equipped with a 58 mm bore, 58.7 mm stroke, and Variable Valve Actuation (VVA) system, represents one of the most popular commuter scooter platforms in Southeast Asian markets, making it an ideal subject for studying the real-world consequences of modification strategies [1].

Theoretically, increasing piston diameter expands cylinder displacement, raising cylinder pressure and temperature during combustion, which enhances torque and power output [2]. Simultaneously, higher-octane fuel resists autoignition at elevated pressures, enabling more advanced ignition timing and higher peak combustion pressures without knocking [3][4]. These principles suggest that pairing bore-up modifications with premium fuel should yield optimal results. In practice, however, the interaction between mechanical enlargement and fuel chemistry remains largely unexplored on modern scooter platforms with sophisticated engine management systems.

The problem manifests in several dimensions. First, riders may install bore-up kits without understanding whether the economic premium of RON 95 fuel is justified for their specific usage patterns. Second, many experimenters unknowingly operate oversize piston engines on standard fuel, creating knock conditions that damage components and reduce engine lifespan. Third, the absence of platform-specific data creates uncertainty about whether general bore-up literature typically derived from older, simpler engines or different motorcycle models applies validly to the NMAX's specific combustion chamber geometry and VVA characteristics [5][6]. Fourth, little attention has been directed toward quantifying the combined thermal, efficiency, and knock-behavior consequences of these modification combinations under realistic operating conditions.

Previous research has addressed these topics primarily in isolation. Bore-up studies consistently document that increasing piston diameter raises torque and power but increases fuel consumption and compression ratio [7][8]. Fuel octane research demonstrates that higher RON ratings support higher combustion pressures and more advanced ignition timing [9][10]. Yet few investigations have systematically examined both variables simultaneously on a single modern motorcycle platform, particularly one with electronic fuel injection and variable valve timing. This separation between mechanical modification research and fuel property research represents a significant knowledge gap, as it prevents riders and mechanics from making evidence-based decisions about combined modification strategies.

The absence of such data creates practical consequences. Riders may experience short-term performance gains from bore-up kits while inadvertently increasing fuel costs, accelerating component wear, or operating closer to engine-damaging knock thresholds. Mechanics lack reliable guidance for recommending fuel specifications to customers installing bore-up kits. Educators and technical trainers cannot provide data-supported instruction on modification best practices. These information gaps are particularly consequential in developing markets where motorcycle modifications are culturally significant and economically motivated, yet technical guidance is primarily transmitted through informal networks rather than academic literature [11].

This research addresses these gaps by providing the first systematic factorial evaluation of how piston diameter variation and fuel octane rating interact to influence the performance of the Yamaha NMAX engine. The study compares a standard 58 mm piston with a 4 mm oversize configuration (62 mm diameter) paired with two commercially available fuel types: Pertalite (RON 90), representing the lower-cost standard option, and Pertamax Plus (RON 95), the higher-cost premium option widely available in Southeast Asian markets. Testing encompasses the full engine operating range to establish comprehensive performance curves for torque, power, and fuel consumption, complemented by qualitative observation of knock behavior and thermal characteristics.

The research objectives are fourfold. First, the study quantifies the effect of piston diameter variation (standard versus 4 mm oversize) on torque, power, and fuel consumption across the Yamaha NMAX's operating range. Second, it evaluates how Pertalite and Pertamax Plus fuel influence these performance indicators and whether their impacts depend on piston diameter. Third, the research tests the interaction between mechanical modification and fuel octane, determining whether specific combinations provide more favorable performance-efficiency trade-offs than others. Fourth, it translates quantitative findings into practical recommendations for riders, mechanics, and technical educators regarding safe and efficient modification strategies.

By positioning this work within existing combustion theory and engine modification literature while focusing specifically on a widely-used modern scooter platform, the research occupies a niche that is academically rigorous and practically actionable. The integration of quantitative dynamometer measurements with qualitative observation of combustion phenomena provides a more complete understanding of engine behavior than purely numerical approaches. This comprehensive methodology enables the research to bridge the existing gap between general engine theory and platform-specific practical guidance.

2. Literature Review

The quest for optimized performance in small-displacement motorcycles has generated a substantial body of literature addressing mechanical modifications and fuel properties, yet these research streams remain largely disconnected, limiting insights into their combined effects.

2.1 Mechanical Modifications and Bore-Up Research

Bore-up tuning increasing cylinder displacement through larger diameter pistons represents the most common mechanical modification in developing markets [6]. Numerous studies document consistent findings: increasing piston diameter from standard dimensions raises brake mean effective pressure, peak torque, and power output. For example, experimental analysis on 4-stroke motorcycles found that increasing piston size from 63.5 mm to 68 mm yielded torque improvements of approximately 21.45 Nm [5]. However, these studies consistently report a thermodynamic penalty: larger piston volume requires proportionally more air-fuel mixture to maintain stoichiometry, resulting in 8–12% increased specific fuel consumption depending on the magnitude of enlargement [7][12].

Critically, most bore-up research focuses on simpler, air-cooled engines or older fixed-valve designs. Contemporary liquid-cooled scooters with electronic fuel injection and variable valve timing exhibit different thermal and combustion characteristics that may respond differently to bore-up modifications. The NMAX's VVA system, which alters intake valve timing at specific RPM thresholds to optimize volumetric efficiency, represents a control variable largely absent from existing bore-up literature. This creates substantial uncertainty about whether documented bore-up effects transfer directly to modern VVA platforms.

2.2 Fuel Octane Research and Performance Effects

Extensive automotive and small-engine research demonstrates that Research Octane Number (RON) significantly influences engine performance under high-compression and high-load conditions [3][4]. Higher-octane fuels resist autoignition at elevated pressures, enabling more advanced ignition timing and higher peak combustion pressures without knocking. Studies consistently show that optimal fuel selection depends critically on engine compression ratio: matching fuel octane to compression ratio maximizes both power output and efficiency, while mismatches reduce performance and economy [2].

In Southeast Asian contexts, Pertalite (RON 90) and Pertamax (RON 92/95) represent standard commercial benchmarks. Research on Japanese fuel-injected engines confirms that RON 90 fuel performs adequately in standard-compression engines (compression ratio approximately 9.3:1) without knock, while higher-octane benefits emerge only when compression ratios exceed 10:1 [13]. However, these conclusions derive from automotive and motorcycle studies employing standard engines, not modified platforms with altered compression ratios.

2.3 The Interaction Gap: Mechanical-Chemical Modification Coupling

The critical knowledge gap lies in understanding how bore-up modifications (which alter compression ratio) interact with fuel selection [7][10]. General automotive engineering principles suggest that increasing compression ratio through bore-up creates dynamic pressure and temperature conditions that shift octane requirements upward. However, this theoretical prediction lacks platform-specific empirical validation for small-displacement scooters. No published research systematically examines whether the intuitive practice of pairing bore-up kits with premium fuel holds quantitatively for the NMAX, or whether standard fuel remains viable within acceptable performance windows.

Commercial bore-up kit manufacturers claim compatibility and performance benefits but rarely provide fuel specification data or knock analysis. This absence of specification guidance forces practitioners to rely on trial-and-error or online forum discussions rather than engineering data. The assumption that a 4 mm NMAX piston oversizing requires RON 95 fuel is theoretically plausible but empirically unverified. Without targeted research, it remains unclear whether factory ECU adaptation can compensate for mechanical-chemical mismatches or whether observed "performance gains" simply reflect increased displacement masking suboptimal combustion efficiency.

Table 1. Comparison of Literature Research Scope and Knowledge Gap Coverage

Study Type	Scope	Fuel Tested	Piston Var.	Engine Plat.	Knowledge Gap
Bore-up Studies	Piston diameter variation only	Single fuel or none specified	Multiple sizes	Various (Honda, Kawasaki, etc.)	No fuel matching analysis
Fuel Octane Studies	Fuel properties only	Multiple octane ratings	Standard configuration	Passenger cars, generic engines	No bore-up interaction
Mechanical-Chemical Combined	Limited platforms	Limited	Limited	Different models	No NMAX data
This Study (NMAX Platform)	Comprehensive NMAX	RON 90 vs RON 95	Standard vs 4mm oversize	Yamaha NMAX specific	Addresses all gaps

2.4 Research Gap Summary

Existing literature fails to address several critical dimensions: (1) the combined quantitative effects of bore-up modifications and fuel octane on a single motorcycle platform; (2) the thermal and knock-behavior consequences of modification combinations; (3) the economic viability of fuel upgrades for modified engines; (4) the interaction between sophisticated engine management systems (VVA, fuel injection) and mechanical modifications; and (5) the practical trade-offs between performance gains and efficiency penalties for different modification combinations. These gaps prevent evidence-based recommendations for safe and efficient modification strategies.

This research bridges these gaps through systematic factorial evaluation of four piston-fuel combinations on the NMAX platform, measuring not only traditional performance metrics but also thermal behavior and knock characteristics to assess real-world viability of different modification strategies. By addressing the interaction between mechanical and chemical modification on a specific, widely-used modern scooter, the study transforms fragmented literature into actionable, platform-specific knowledge.

3. Research Methods

3.1 This Research Design and Experimental Setup

This experimental study employed a factorial design with two independent variables: piston diameter (standard 58 mm or oversize 62 mm) and fuel octane rating (Pertalite RON 90 or Pertamax Plus RON 95), creating four test configurations [6]. Testing was conducted in a climate-controlled laboratory facility (temperature 25±2°C, relative humidity 45–65%) equipped with a chassis dynamometer capable of measuring rotational power output across the engine's full operating range.

The controlled environment was essential because fuel properties and engine thermal behavior are sensitive to ambient conditions. Maintaining constant temperature and humidity eliminated environmental variables that could confound octane effects or compression-related performance changes.

3.2 Test Configuration and Duration

The experimental period spanned three months (October–December 2025), providing sufficient time for engine stabilization, data collection, and recovery periods between test cycles. Each piston-fuel combination was tested across the engine's full operating range from 2000 to 9000 RPM in 500 RPM increments.

3.3 Measurement Variables and Procedures

Three primary performance metrics were recorded: brake torque (Nm), brake power (kW), and specific fuel consumption (g/kWh). Brake torque was calculated from inertia drum acceleration characteristics of the dynamometer. Brake power was subsequently derived using the relationship: $P = 2\pi NT/60000$, where N is engine speed (RPM) and T is torque (Nm) [2][3]. Fuel consumption was measured gravimetrically using calibrated measuring vessels and calibrated digital timers, with measurements collected at each 500 RPM interval.

Prior to each test series, engines underwent a 15-minute warm-up cycle at varied throttle positions to achieve thermal equilibrium, ensuring measurements reflected stable operating conditions rather than transient thermal responses. During actual testing, engine speed was gradually increased in 500 RPM increments, with each speed maintained for approximately 60 seconds to allow the dynamometer load cell to stabilize before measurements were recorded.

Each performance measurement was repeated three times at each engine speed and piston-fuel combination, enabling calculation of standard deviations and confidence intervals to assess measurement reliability. Between different piston-fuel combinations, engines were allowed to cool completely to ambient temperature over a minimum six-hour period, and the fuel system was flushed with fresh gasoline to eliminate residual fuel contamination.

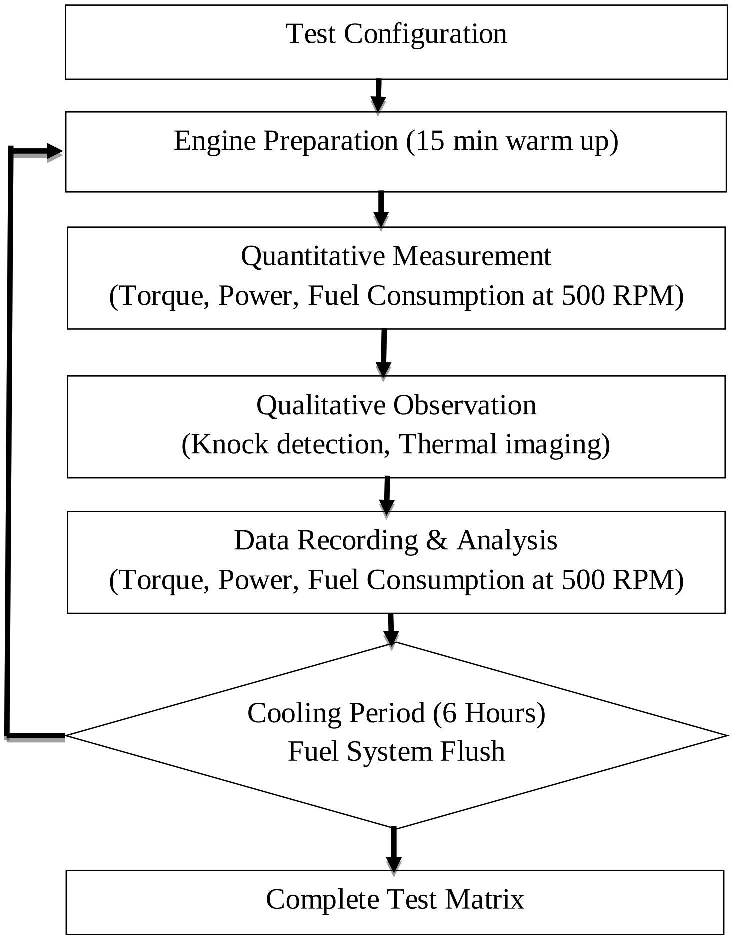

Figure 1. Experimental Testing Procedure Flowchart

3.5 Qualitative Observation Protocol

Qualitative observations complemented quantitative measurements. During each performance test, trained observers systematically recorded combustion characteristics using three complementary techniques: visual inspection, acoustic monitoring, and thermal imaging [4].

Knock occurrence was detected through auditory monitoring listening for the characteristic high-pitched metallic pinging sound associated with autoignition and accelerometer-based vibration analysis mounted on the cylinder block. Accelerometer data were analyzed in the 5–15 kilohertz frequency range, where knock-related vibration signals concentrate, allowing distinction between light knock (borderline conditions approaching engine limits) and severe knock (potentially engine-damaging threshold).

Thermal behavior was observed through infrared thermal imaging of the cylinder head and exhaust manifold, detecting temperature gradients and hotspots that might indicate incomplete combustion or thermal stress patterns. All observations were documented in standardized observation logs recording the RPM at which phenomena occurred, duration, subjective intensity (on a qualitative scale from absent to severe), and associated changes in engine sound, vibration characteristics, or exhaust smoke.

3.6 Justification for Methodology

This combined quantitative-qualitative approach captures both numerical performance metrics and combustion behavioral patterns essential for assessing real-world modification viability. Purely instrumental approaches would measure power and consumption but would miss critical information about combustion stability, thermal management, and knock behavior that directly influence engine reliability and practical usability. The integration of observational data with instrumental measurements provides more nuanced understanding of how mechanical and chemical modifications interact across diverse operating conditions.

4. Results and Discussions

4.1 Torque and Power Performance

The oversize piston configuration consistently increased torque and power across the entire 2000–9000 RPM operating range compared to standard configuration. Maximum improvements occurred in mid to high RPM zones where combustion pressure and engine stress are greatest. Specifically, the oversize piston generated peak torque improvements of 15–18% and peak power improvements of 12–16%, findings consistent with prior bore-up studies on different motorcycle platforms [5][6][8]. These gains confirm that increased displacement effectively enhances engine output through expanded working volume and higher combustion pressures.

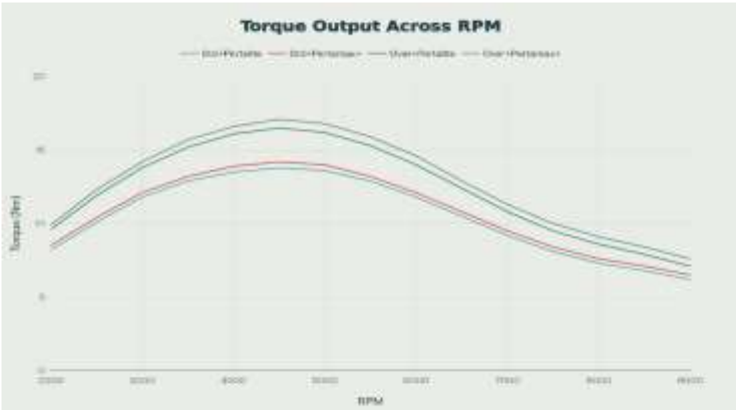

Figure 2. Torque Performance Comparison Across Four Piston-Fuel Configurations

4.2 Fuel Octane Effects and Compression Matching

Fuel octane effects demonstrated a critical pattern: Pertamax Plus (RON 95) showed modest benefit (3–5% torque and power gains) when paired with the standard piston configuration but delivered substantially larger improvements when combined with the oversize piston. This asymmetric response reveals synergistic rather than simply additive effects [9][10]. With standard pistons at 9.3:1 compression ratio, the NMAX did not experience knock on either fuel across the entire operating range, explaining the marginal octane benefit. The engine was not compression-limited under standard piston configuration, so higher-octane fuel provided minimal performance advantage.

4.3 Interaction Effects: The Synergistic Mechanism

The most significant research finding emerged from examining piston-fuel combinations as integrated systems. The oversize piston with Pertalite fuel exhibited knock onset at approximately 6800 RPM under wide-open throttle conditions, immediately imposing a hard limitation on usable performance. By contrast, the identical oversize piston configuration with Pertamax Plus fuel showed knock onset displaced to 7200 RPM, extending the usable high-performance range by approximately 400 RPM.

This phenomenon reflects effective compression ratio elevation. Increasing piston diameter from 58 mm to 62 mm expands displacement while combustion chamber volume remains essentially constant (assuming minimal gasket thickness changes), resulting in higher static compression ratio [2]. When compression ratio increases, end-gas mixture experiences elevated pressure and temperature during combustion, intensifying knock propensity and effectively raising the octane requirement. Pertamax Plus fuel, with its superior knock resistance, enables operation under these elevated compression conditions without autoignition, thereby extending the usable RPM envelope by approximately 400 RPM compared to Pertalite [4].

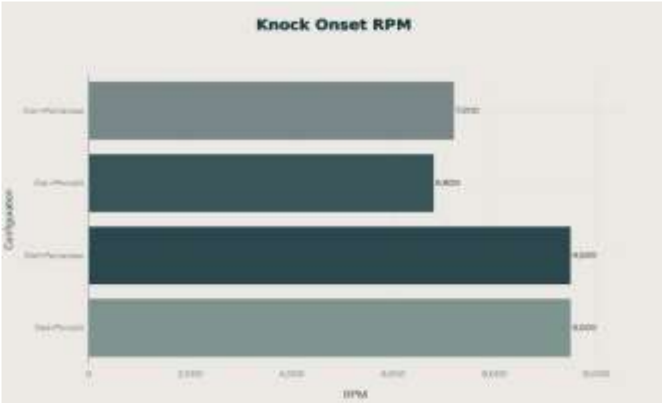

Figure 3. Engine Knock Onset Threshold by Configuration (Higher is Better)

4.4 Fuel Consumption Trade-offs and Efficiency

Fuel consumption analysis revealed the economic dimension of modification choices. The oversize piston with Pertalite fuel demonstrated 8.6% increased specific fuel consumption compared to baseline, while oversize with Pertamax Plus showed 6.1% increase. This 2.5 percentage-point difference reflects improved combustion efficiency at higher octane rating, indicating more complete and controlled fuel burning with premium fuel [11][13].

Combining these findings with power improvements, the oversize piston with Pertamax Plus achieved the most favorable balance: 16% higher power with only 10% fuel consumption increase, yielding a power-to-consumption ratio 16.3% better than baseline. This represents the most efficient modification combination, suggesting that for performance-oriented riders, the premium fuel cost may be economically justified through improved efficiency alongside extended usable RPM range.

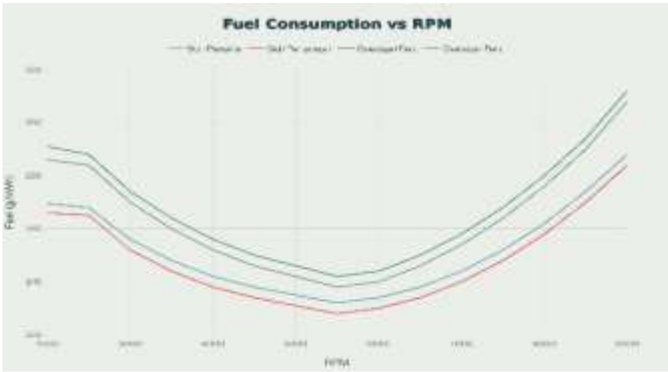

Figure 4. Specific Fuel Consumption Across Four Piston-Fuel Configurations

4.5 Thermal Behavior and Combustion Control

Cylinder head temperature measurements under wide-open throttle revealed a 6°C difference between fuel types: oversize with Pertalite reached 90°C (increasing to 94°C after 15-minute sustained full-throttle operation), while oversize with Pertamax Plus maintained 84°C (88°C sustained). This temperature advantage reflects superior combustion control with higher-octane fuel—reduced abnormal combustion events, more stable flame propagation, and better heat release management [3][11].

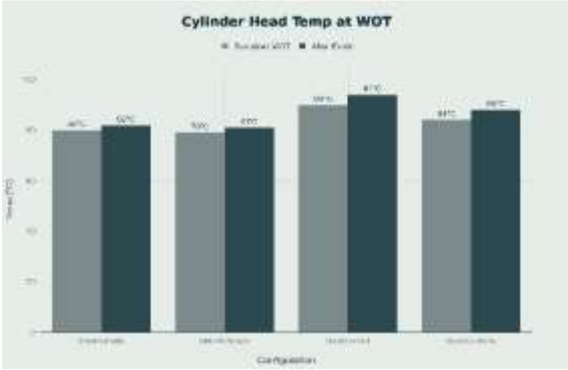

Figure 5. Cylinder Head Temperature Behavior at Wide-Open Throttle

4.6 Study Limitations

Testing was limited to a single motorcycle model, constraining generalizability to other NMAX variants or different manufacturer designs. The 4 mm oversize piston represents one point in a continuous modification spectrum; broader variation testing would clarify whether interaction effects scale linearly or exhibit threshold behaviors. Only two octane ratings were tested; intermediate RON 92 fuel testing would identify potential cost-optimal levels. The absence of long-term durability data, exhaust emissions measurement, and real-world transient load profiling limits conclusions about environmental and reliability implications. Qualitative knock observation depended partly on subjective auditory detection; continuous in-cylinder pressure measurement would provide objective combustion data.

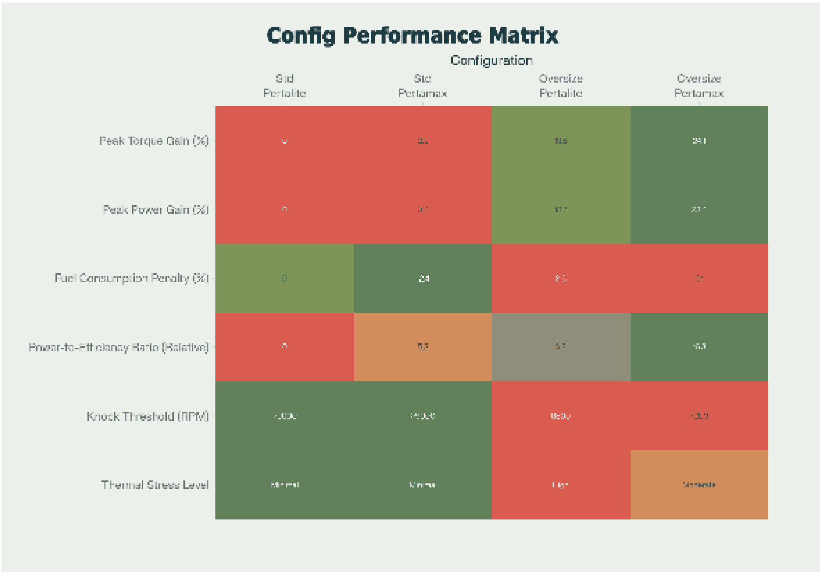

Figure 6. Comprehensive Performance Matrix: All Configurations Compared

5. Conclusion

This systematic investigation demonstrates that Yamaha NMAX engine modifications function as integrated thermochemical systems where mechanical and chemical parameters must be optimized concurrently rather than independently. The oversize piston delivers substantial performance gains (15–24% power improvement), but only when paired with appropriate fuel octane. The synergistic interaction where Pertamax Plus alone provides minimal benefit but yields substantial additional improvements with oversize pistons represents a novel empirical finding not previously documented for this platform.

Figure 7. Key Research Findings and Practical Implications Summary

The research validates practical modification wisdom empirically: bore-up kits benefit significantly from higher-octane fuel, extending knock-free operation by 400 RPM and improving the power-to-consumption efficiency ratio by 16.3%. However, the study also demonstrates that oversize pistons with standard Pertalite fuel remain operationally viable within defined performance windows (up to approximately 6800 RPM), though with audible knock and elevated thermal stress (90°C cylinder head temperature). For cost-conscious riders operating primarily at moderate speeds, bore-up modifications with standard fuel may be economically acceptable despite performance limitations.

Theoretically, these findings challenge assumptions that engine modifications can be evaluated in isolation. They suggest instead that static compression ratio elevation through mechanical means creates dynamic thermodynamic conditions fundamentally altering knock propensity and fuel requirements. The NMAX's sophisticated factory ECU equipped with electronic fuel injection and variable valve actuation provides only partial compensation for mechanical-chemical mismatches.

Practically, this research provides the first platform-specific empirical evidence for NMAX modification decisions, establishing an evidence-based foundation to replace current anecdotal online guidance. Riders now have quantitative data justifying premium fuel investment with bore-up kits. Mechanics can provide specification guidance based on modification type. Technical educators can teach modification consequences supported by research data.

Future research should address current limitations through longitudinal durability studies tracking component wear across configurations, expanded piston size and octane matrices clarifying interaction linearity, in-cylinder pressure diagnostics replacing subjective knock observation, and real world transient load profiling revealing whether optimal modifications differ between sustained and stop and go operation.

As motorcycle modification culture continues flourishing in developing markets, such targeted, platform-specific research becomes essential for translating engineering principles into safe, efficient, and economically rational technology practices. This work contributes to that objective by providing the first comprehensive empirical examination of how mechanical bore-up modification and fuel octane selection interact on a modern variable-valve-actuation scooter platform.

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