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Cross Kart with A Single-Cylinder Si Engine Featuring Supercharger & Turbocharger

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ABSTRACT: *The integration of twin-charging – combining a supercharger and a turbocharger – on a single-cylinder spark-ignition (SI) engine for a cross-kart vehicle offers a novel approach to enhancing power output and efficiency. This work focuses on optimizing the forced-induction system to overcome the inherent limitations of single-cylinder engines, such as low torque and power across varying RPM ranges. The supercharger supplies immediate low-end boost and reduces turbo lag, while the turbocharger enhances high-speed performance by utilizing exhaust energy. A 220 cc Bajaj Avenger single-cylinder SI engine was mounted on a custom tubular-chassis cross-kart and evaluated on a dynamometer under naturally aspirated, supercharger-only, turbocharger-only and twin-charged configurations. The twin-charged configuration increased brake power by 28.57%, thermal efficiency by 21.75% and volumetric efficiency by 16.47% over the stock engine, while a bypass-valve-controlled hybrid boost transition minimized turbo lag. The results confirm that twin-charging is a viable strategy for enhancing the performance of small-displacement engines used in off-road and motorsport applications.*

KEYWORDS: *cross-kart, dynamometer testing, single-cylinder SI engine, supercharger, turbocharger, twin-charging*

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I. INTRODUCTION

Twin-charging, which integrates both a supercharger and a turbocharger, has gained significant attention in high-performance and small-displacement engines. A turbocharger delivers high-end power by harnessing exhaust gases, while a supercharger provides instant boost at low RPM by mechanically driving air into the intake. Combining the two eliminates turbo lag and produces a consistent power curve across the entire RPM range. Cross-kart buggies are lightweight, high-performance off-road vehicles that demand rapid acceleration, a high power-to-weight ratio and superior handling on rough terrain; naturally aspirated single-cylinder engines often cannot deliver the required power without an increase in displacement and weight. This work presents the design, fabrication and dynamometer-based performance evaluation of a twin-charged single-cylinder SI engine installed in a cross-kart, with the objective of improving low-end torque, high-speed power and overall efficiency while retaining a lightweight, compact powertrain.

II. LITERATURE REVIEW

Forced induction has long been recognized as an effective means of improving the power density and volumetric efficiency of internal combustion engines, and a growing body of research has extended these strategies from conventional multi-cylinder automotive applications to small and single-cylinder engines, where packaging constraints and low-speed torque deficits present unique challenges. Bisane et al. [1] investigated the application of super-turbocharging—a hybrid boosting configuration combining a mechanically driven supercharger with an exhaust-driven turbocharger—on a single-cylinder diesel engine. Their experimental results showed that this configuration increased brake power by 48.9% and volumetric efficiency by 39.17% at 50% loading, demonstrating that combined boosting strategies, traditionally reserved for larger multi-cylinder units, can be adapted to single-cylinder platforms with substantial performance gains. This work established an important precedent that single-cylinder engines are not inherently limited to single-stage or naturally aspirated operation. Abdul Azeez and Khan [2] provided a broader review of supercharger and turbocharger technologies, comparing centrifugal, roots-type, and screw-type compressors alongside fixed-geometry and variable-geometry turbochargers. Their review synthesized the trade-offs between these devices in terms of transient response, parasitic losses, and their combined influence on exhaust emissions and delivered power, offering a technology-selection framework relevant to engines of varying displacement. Saini et al. [3] narrowed this scope further by experimentally fitting a turbocharger to a 125 cc single-cylinder motorcycle engine, a displacement class rarely subjected to forced induction in practice. Their study demonstrated measurable gains in volumetric efficiency, confirming that even very small-displacement engines can benefit from exhaust-driven boosting, though such configurations are typically constrained by turbo lag at low engine speeds due to the limited exhaust energy available from a single cylinder. Moving to multi-cylinder applications, MAHLE Powertrain [4] and Tziakis et al. [5] examined twin-charging the combination of a positive-displacement supercharger for low-speed boost with a turbocharger for high-speed boost-as a downsizing strategy. Their studies showed that twin-charged, downsized multi-cylinder engines could achieve higher specific power output while simultaneously reducing CO_2 emissions relative to larger naturally aspirated counterparts, reinforcing twin-charging's appeal as a fuel-economy and emissions-compliance strategy. This was corroborated by real-world production evidence from Volkswagen's 1.4 TSI engine [9], a commercially successful twin-charged unit that delivered power output comparable to a larger-displacement engine while achieving improved fuel economy, validating the twin-charging concept outside the laboratory. Complementing these performance-focused studies, Gazella and Bonfanti [6] and Agarwal et al. [7] discussed control strategies for boosting systems more broadly, including bypass valve management, boost pressure regulation, and the coordination between supercharger clutch engagement and turbocharger wastegate control—factors critical to smooth transition between boosting modes and to avoiding compressor surge or overboost conditions. The theoretical and thermodynamic foundation for this body of work draws on standard references in engine and turbocharging theory: Stone [8], Pulkrabek [10], and Heywood [11] provide the fundamental thermodynamic cycle analysis, volumetric efficiency definitions, and combustion modeling underpinning internal combustion engine performance evaluation, while Watson and Janota [12] offer a dedicated treatment of turbocharging theory, compressor-turbine matching, and boost system design principles.Several studies have examined forced-induction strategies for small and single-cylinder engines.

Taken together, these studies establish that both super-turbocharging and twin-charging can substantially improve power output and volumetric efficiency, and that twin-charging in particular offers a proven pathway to downsizing with emissions benefits in multi-cylinder engines. However, despite this progress, the literature reveals a clear gap: twin-charging has been extensively studied and commercially validated for multi-cylinder engines, but its application to compact single-cylinder engines remains comparatively unexplored. Specifically, long-term durability data under twin-charged operating conditions, standardized test protocols for evaluating such systems on single-cylinder platforms, and dedicated control-system studies addressing the unique low exhaust-energy characteristics of a single cylinder are all limited in the existing body of work. This gap motivates the present investigation into twin-charging strategies for compact single-cylinder engines.

III. METHODOLOGY AND MATERIALS

3.1 Design Procedure of the Cross-Kart

A tubular space-frame chassis was selected for its favourable strength-to-weight ratio and ease of fabrication. The chassis was modelled in CAD software with a mid-rear engine layout to improve traction and weight distribution, and validated by Finite Element Analysis (FEA) under torsional and impact loading. Mild-steel (G.I.) tubes of 20–25 mm outer diameter and 2 mm wall thickness were cut, bent and joined by MIG welding using a jig to preserve dimensional accuracy. A double A-arm front suspension with a trailing-arm/solid-axle rear, rack-and-pinion steering, four-wheel hydraulic disc brakes and a chain-driven rear axle complete the running gear.

3.2 Engine and Twin-Charging System

A 220 cc Bajaj Avenger single-cylinder, 4-stroke, air-cooled SI engine (Table 1) was selected for its compact size and adaptability to forced induction. The supercharger was belt-driven from the crankshaft on a custom bracket to provide immediate low-RPM boost, while a turbocharger sourced from a small-displacement diesel engine was coupled to a custom exhaust manifold to exploit exhaust energy at mid-to-high RPM. A bypass valve routed intake air between the two compressors according to engine speed and load, an air-to-air intercooler reduced intake-air temperature to prevent knock, and a blow-off valve and wastegate regulated boost pressure.

Table 1: Engine specifications

Parameter	Specification
Engine type	Single-cylinder, 4-stroke, air-cooled, DTS-i
Displacement	220 cc
Bore × Stroke	67 mm × 62.4 mm
Compression ratio	9.5 : 1

Parameter	Specification
Maximum power	19.03 PS @ 8,400 rpm
Maximum torque	17.55 Nm @ 7,000 rpm
Fuel system	Carburettor (UCAL BS29)
Transmission	5-speed constant mesh

IV. EXPERIMENTAL PROCEDURE

4.1 Fabrication and Test Setup

Following FEA validation, the chassis (Fig. 1) was fabricated and the engine, supercharger, turbocharger, intercooler and drivetrain were mounted. The completed cross-kart was tested in four configurations – naturally aspirated (stock), supercharger-only, turbocharger-only and twin-charged – on an engine dynamometer at progressively increasing brake loads.

Fig. 1: Fabricated cross-kart with the twin-charged single-cylinder engine

4.2 Performance Parameters

For each trial, load (N) was obtained from the applied brake mass, torque $T = r \times Load$ ($r = 0.07$ m effective radius), and brake power $BP = 2\pi NT / 60$. Brake specific fuel consumption was computed as $BSFC = \dot{m}_{fuel} / BP$, thermal efficiency as $\eta_{th} = (BP / (\dot{m}_{fuel} \times CV)) \times 100$, and volumetric efficiency as $\eta_v = (\dot{m}_{air} R T) / (P V_d N) \times 100$, where CV is the calorific value of petrol and V_d is the swept volume per cycle.

V. RESULTS AND DISCUSSION

Table 2 compares the highest-load trial (12 kg brake mass) recorded for each configuration. The twin-charged engine consistently outperformed the individually boosted and naturally aspirated configurations across brake power, thermal efficiency and volumetric efficiency, while its BSFC was substantially lower, indicating more complete combustion of the admitted charge.

Table 2: Performance comparison at maximum test load (12 kg)

Configuration	RPM	BP (kW)	BSFC (kg/kWh)	Thermal Eff. (%)	Vol. Eff. (%)
Naturally aspirated	1450	5.99	1.23	21.85	62.25
Supercharger only	1450	5.99	1.23	22.71	67.35
Turbocharger only	1470	1.26	1.00	23.40	69.10
Twin-charged	1550	13.36	0.574	24.60	70.90

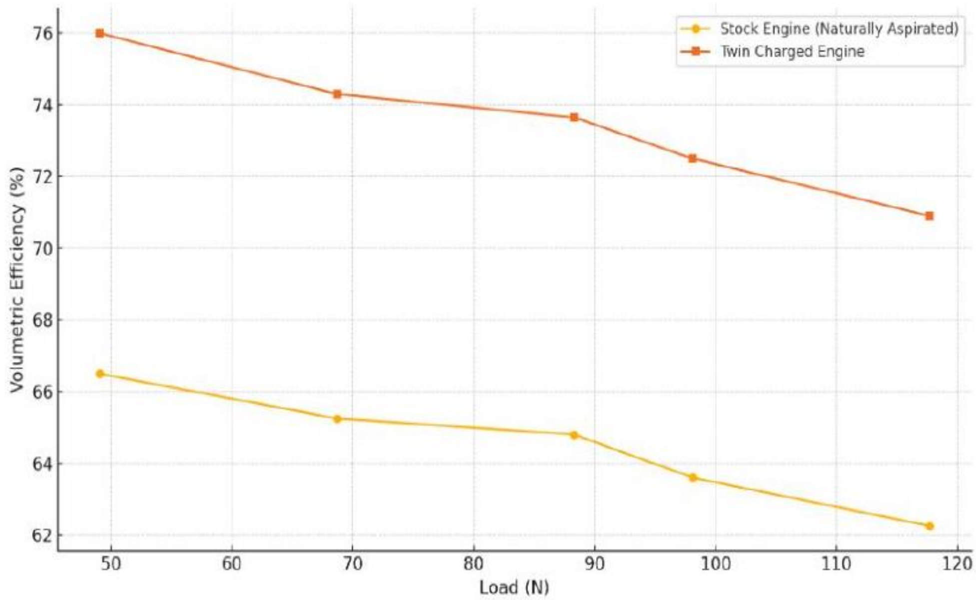

Fig. 2: Load vs. volumetric efficiency – stock vs. twin-charged engine

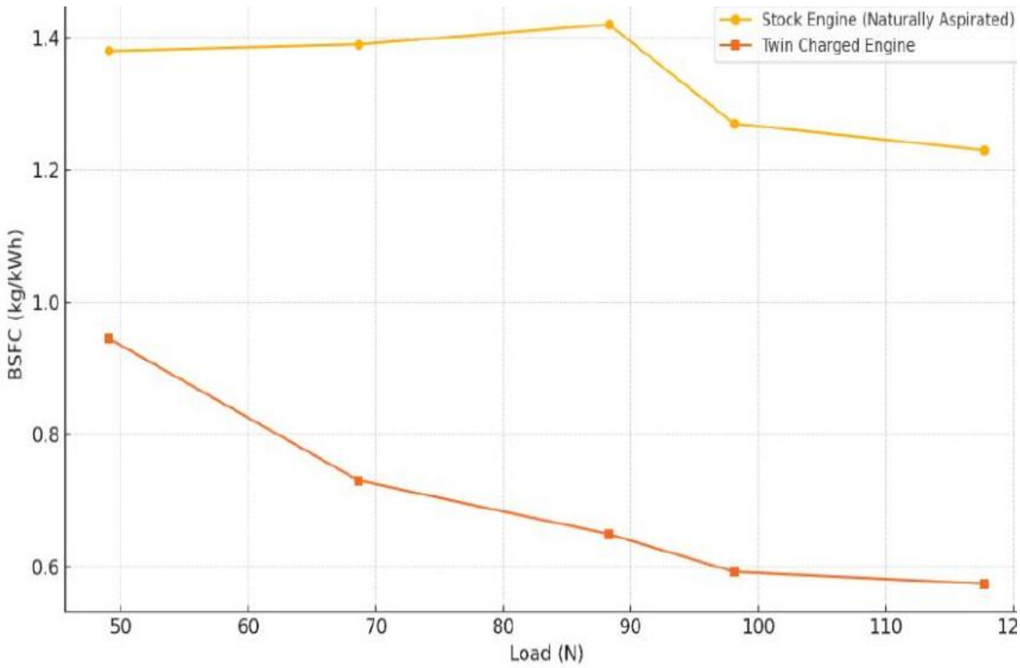

Fig. 3: Load vs. brake specific fuel consumption – stock vs. twin-charged engine

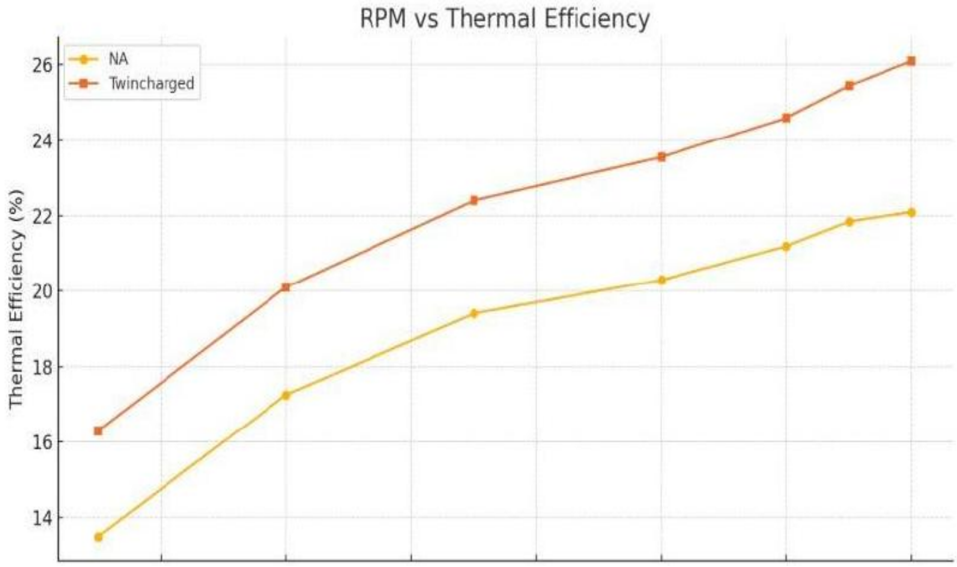

Fig. 4: Load vs. thermal efficiency – stock vs. twin-charged engine

The heat-balance analysis (Table 3) shows that the share of heat converted to brake power rose from 17.02% in the stock engine to 17.31% in the twin-charged configuration, while the twin-charged engine also showed a higher proportion of unaccounted heat losses (22.69%), attributable to the additional intercooling and boost-control hardware. Overall, twin-charging raised brake power by 28.57%, thermal efficiency by 21.75% and volumetric efficiency by 16.47% relative to the stock engine, confirming that the supercharger effectively removed turbo lag while the turbocharger sustained high-RPM output.

Table 3: Heat balance – naturally aspirated vs. twin-charged (kJ/hr, %)

Debit	Naturally Aspirated	Twin-charged
Heat equivalent to BP	15,120 (17.02%)	17,280 (17.31%)
Heat in cooling water	24,800 (27.91%)	24,948 (25.00%)
Heat in exhaust gases	36,800 (41.41%)	34,920 (35.00%)
Heat unaccounted	11,800 (13.29%)	22,652 (22.69%)

VI. CONCLUSION

A twin-charging system combining a supercharger and a turbocharger was successfully designed, fabricated and evaluated on a 220 cc single-cylinder SI engine mounted in a cross-kart. The supercharger provided instant low-RPM boost while the turbocharger sustained high-speed power, and a bypass valve managed the transition between the two, reducing turbo lag. Dynamometer testing showed increases of 28.57% in brake power, 21.75% in thermal efficiency and 16.47% in volumetric efficiency relative to the naturally aspirated engine. Although the twin-charging hardware introduces additional mechanical and control complexity and modest extra heat loss, the results confirm that twin-charging is a technically feasible and effective means of enhancing the performance of small-displacement single-cylinder engines for off-road and motorsport applications. Future work will incorporate digital sensors and a data-acquisition system for real-time monitoring, and will explore common-rail or variable-timing fuel injection to further improve combustion efficiency and emissions.

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