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From pressure to performance: Engineering the vane flow air bike

Akshar Patil, Henisha Raut, Durgasingh Chundavath, Paras Pagdhare, Sairaj Shinde
Department of Mechanical Engineering, VIVA Institute of Technology, Virar, Maharastra, India

Abstract
Transportation plays a vital role in modern society; however, conventional vehicles powered by fossil fuels significantly contribute to environmental pollution and the depletion of natural resources. This research investigates a sustainable and eco-friendly alternative: a compressed air-powered vehicle that operates without gasoline or electricity. By harnessing pneumatic propulsion, the study presents a zero-emission mode of transport suitable for urban mobility.
The core of this study involves the design, development, and performance evaluation of a vehicle driven by a vane-type pneumatic motor, supported by a high-pressure air storage system and an optimized transmission mechanism. The vehicle is engineered to maintain structural durability while ensuring efficient energy conversion and smooth functionality. Performance testing assesses critical parameters such as speed, range, and air consumption.
While the prototype demonstrated promising outcomes, certain limitations including air leakage, mechanical losses, and the inherently low energy density of compressed air impacted efficiency. The study recommends future improvements such as increasing air storage capacity, enhancing sealing systems, and integrating hybrid mechanisms to extend operational range. These findings contribute to the broader pursuit of sustainable transportation technologies and highlight the potential of compressed air propulsion as a viable alternative for short-distance urban travel.

Keywords: Compressed air vehicle, sustainable transportation, vane-type pneumatic motor, urban mobility, zero-emission

Introduction

Transportation is essential in our modern lives, but its reliance on fossil fuels has caused significant environmental problems, including pollution and resource depletion. The Design and Fabrication of the Vane Flow Air Bike project aims to offer a suitable solution by utilizing compressed air as the propulsion system. This eco-friendly alternative addresses the urgent need to reduce carbon emissions and dependency on conventional fuels. This project examines the potential of utilizing compressed air to power pneumatic motors, thereby eliminating the need for gasoline or electricity. With zero emissions and exhaust, the air-powered bike provides an effective solution and a cleaner mode of transportation. 1.1 Project Background the Vane flow Air bike project focuses on creating a sustainable alternative to gasoline powered and electric vehicles by employing compressed air as the propulsion mechanism. As environmental concerns related to pollution and fuel depletion grow, there is a pressing need for innovative transportation solutions. The Vane flow Air bike project addresses these concerns by using compressed air stored in high-pressure tanks to drive a pneumatic motor that powers 2 the wheels. Unlike traditional internal combustion engines, the pneumatic motor operates without producing exhaust emissions, resulting in a cleaner, greener mode of transport. Compressed air is readily available, inexpensive, and renewable, making it an ideal energy source for eco-friendly transportation. By removing reliance on fossil fuels and electricity, the air-powered bike significantly lowers its operational costs and carbon footprint.

1.1 Project Background

The Vane Flow Air Bike project centers on the development of a compressed air-driven transportation system, intended to replace conventional gasoline-powered and electric two-wheelers. Amid escalating environmental concerns and the finite nature of fossil fuels, there is an urgent need for sustainable propulsion technologies. This project proposes the use of compressed air stored in high-pressure tanks to drive a pneumatic motor, which in turn powers the vehicle's wheels.

Unlike traditional internal combustion engines that emit harmful gases, the pneumatic system operates with zero emissions, offering a clean, quiet, and renewable mode of transportation. Compressed air is not only widely available and cost-effective but also eliminates the environmental and economic burdens associated with fossil fuel extraction and electricity generation. Furthermore, the operational costs of air-powered vehicles are substantially lower, making this technology a promising candidate for affordable and sustainable urban mobility.

By leveraging the simplicity and efficiency of pneumatic mechanisms, the Vane Flow Air Bike exemplifies how clean energy solutions can be practically implemented in everyday transportation, reducing the global carbon footprint and fostering environmental stewardship.

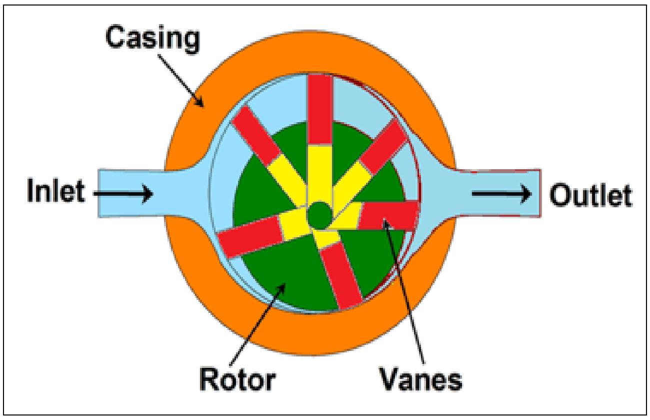

Fig 1: Vane Type Air Motor [Google]

Literature survey

Compressed air as an alternative energy source for transportation has gained significant attention in recent years due to growing environmental concerns and the need to reduce dependence on fossil fuels. The following studies provide critical insights into the development, performance, and viability of compressed air-powered vehicles, particularly bicycles and motorcycles.

Akpan *et al*. (2024) developed a modified bicycle powered by a compact internal combustion engine, achieving an average speed of 23.44 km/h. Their prototype demonstrated practical potential in low-resource settings, though they recommended enhancements such as gear integration to boost performance and commercial appeal. Local material sourcing was emphasized to reduce costs and improve regional adaptability [1].

Jankowski *et al*. (2024) demonstrated that pneumatic power significantly enhanced bicycle RPM—showing a 2.74-fold increase at 5-bar pressure. Their system aimed to reduce pedaling effort, offering a viable solution for urban commuters [2].

Marko (2024) assessed the practicality of compressed air propulsion through simulations and experiments. Despite identifying low energy density—about 90 times less than gasoline—as a key limitation, he advocated for CAEs in short-distance, low-load applications, stressing energy loss reduction [3].

Zeng *et al*. (2023) focused on optimizing air storage and energy conversion in CAE systems. Their findings indicated that improving these aspects could significantly increase the viability of compressed air vehicles in urban settings [4].

Deshpande (2022) created a compressed air-powered bike prototype that cut emissions without sacrificing performance. He emphasized enhancing energy recovery and air storage to extend range and improve daily usability [5].

Kumar *et al*. (2021) developed a cost-effective pneumatic bike tailored for congested urban areas. Highlighting reduced greenhouse gas emissions, they stressed the importance of efficient air utilization and mechanical performance [6].

Papson *et al*. (2020) addressed the primary challenge of energy loss during compression by proposing hybrid models using renewable energy for air compression. Their work highlighted the role of improved thermal management and storage for expanding CAE application [7].

Abd-Elhady *et al*. (2019) successfully converted a four-stroke petrol engine into a compressed air engine, reaching 9.6% efficiency at 8-bar pressure. They recommended better airflow design and innovative materials to enhance performance [8].

Almarqabi *et al*. (2018) designed a pneumatic-assisted bike that improved uphill and sprinting performance. Their design proved effective over short distances and promoted the use of pneumatic boosters in hybrid systems [9].

Tiwari *et al*. (2018) introduced a hybrid bicycle powered manually and pneumatically using a slider-crank mechanism. Equipped with a pressure gauge and flow regulator, their design reduced physical exertion and offered a green, low-cost transport solution [10].

Singh (2017) investigated converting a four-stroke engine into a two-stroke air engine using durable materials. The study demonstrated lower emissions and highlighted compressed air's potential for low-power urban vehicles [11].

Saivardhan (2017) explored the full elimination of combustion in pneumatic engines. His work underscored the clean, pollution-free nature of such systems and recommended their integration into hybrid electric vehicles [12].

Mehta and Patel (2016) demonstrated a compressed air bike producing 10.96 kW at 9.25 bar. Their low-cost, low-maintenance system, free of combustion processes, aligned well with urban mobility goals [13].

Singh and Singh (2010) developed a 4-kW vane-type air turbine engine capable of powering motorcycles for short trips. They estimated a 50–60% reduction in emissions compared to gasoline engines, supporting its suitability for developing regions [14].

Sancken and Li (2009) provided foundational research on air motor-compressor system efficiency. They proposed an "open accumulator" design to increase energy density and improve performance in vehicular applications [15].

4.1 Market Survey

A detailed market survey was conducted to assess consumer attitudes toward sustainable transportation solutions. Growing environmental concerns and increasing fuel prices have led to a shift in user preference toward cleaner alternatives. Survey results revealed strong interest in air-powered and electric vehicles, which offer low emissions and reduced operating costs.

Competitor analysis indicated that while electric bikes dominate the green mobility segment, air-powered vehicles are emerging as a viable zero-emission alternative. Their advantages include simplified mechanics, cost-effectiveness, and environmental sustainability, positioning them as a strategic solution in eco-conscious markets.

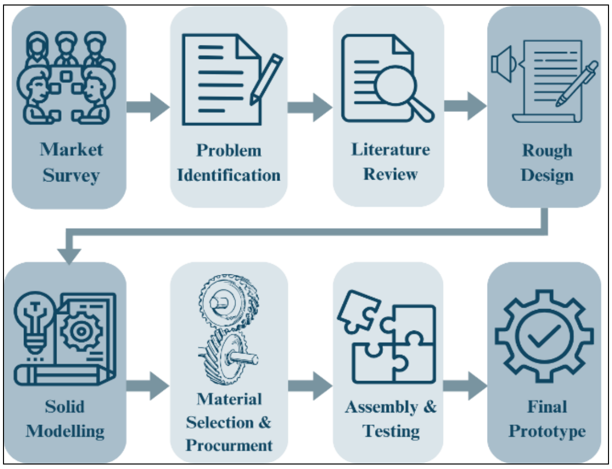

Fig 1: Flowchart

4.2 Problem Statement

Fuel-powered motorcycles significantly contribute to air pollution and incur high operational costs. As outlined in previous chapters, urban transportation needs a shift toward cleaner technologies. The *Vane Flow Air Bike* aims to eliminate fossil fuel dependence, reduce emissions, and provide a cost-effective transportation option using compressed air propulsion technology.

4.3 Literature Review

A comprehensive literature review (Chapter 2) informed the technological framework for this project. Key findings from studies on pneumatic vehicles were used to shape decisions on component selection and system integration. A SWOT analysis identified core strengths such as zero emissions and clean energy utilization, while also recognizing challenges like low energy density and system leakage. Opportunities include urban demand for sustainable mobility, whereas threats involve competition from electric and hybrid alternatives.

4.4 Rough Design
The initial concept incorporated:
- A vane-type pneumatic motor,
- A high-pressure air tank for energy storage,
- An aerodynamic chassis for optimal performance.

The Bajaj Caliber 115 chassis was selected for its structural reliability and adaptability. The early sketches and models emphasized lightweight design, user safety, and smooth operation.

4.5 Solid Model
Using SolidWorks 2023, a full-scale solid model of the Vane Flow Air Bike was created. The model includes the chassis, motor, transmission system, air tank, and connecting pneumatic components. Simulation and analysis tools were applied to ensure proper load distribution, mechanical stability, and dynamic response.

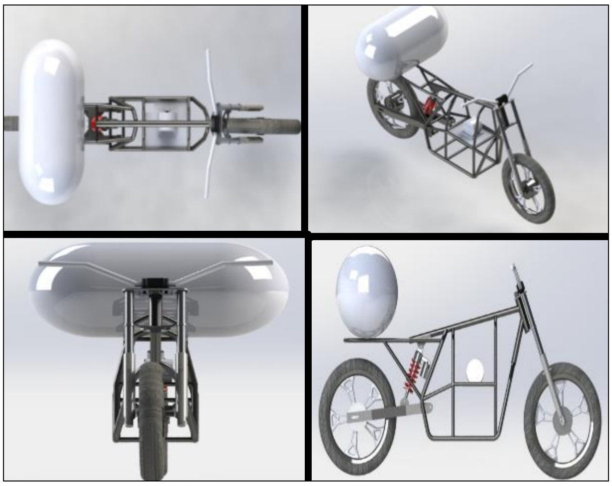

Fig 2: CAD Model [Solidworks 2023]

4.6 Material Selection and Procurement
The selection and procurement of materials for the *Vane Flow Air Bike* were driven by a core focus on achieving optimal strength-to-weight ratios, durability under high pressure, and overall system reliability. Each component of the pneumatic propulsion system and the supporting chassis was selected with careful consideration of its operational role, exposure to mechanical stress, environmental conditions, and integration with other subsystems. The materials and components used were either custom-fabricated or sourced from commercial suppliers based on performance ratings, cost efficiency, and compatibility with pneumatic engineering standards.

4.6.1 Frame and Structural Components
The primary frame of the Vane Flow Air Bike is based on a modified Bajaj Caliber 115 chassis, chosen for its pre-engineered load-bearing capacity and ergonomic geometry. The frame modifications were executed using Mild Steel (MS), a material known for its excellent weldability, mechanical strength, and cost-efficiency. To reduce overall weight without compromising strength, certain non-load-bearing parts were fabricated from aluminum alloy sheets, which offer corrosion resistance, improved handling performance, and reduced inertial load during motion.

4.6.2 Air Tank
The air tank is a central component in the pneumatic energy storage system, responsible for safely containing high-pressure compressed air. A cylindrical mild steel (MS) tank was selected, rated for a working pressure of up to 300 psi, with a sufficient safety margin as per ASME boiler and pressure vessel standards. Mild steel provides excellent ductility and tensile strength, making it suitable for containing pressurized gases without risk of rupture under standard operational conditions. Prior to integration, the tank was subjected to hydrostatic testing and leak-proofing procedures to validate its structural integrity and safety compliance.

4.6.3 Vane-Type Pneumatic Motor

Fig 3: Air Tank [Google]

The pneumatic motor is the core propulsion unit, responsible for converting the energy stored in compressed air into mechanical rotary motion. A vane-type rotary pneumatic motor was selected for its simplicity, high torque output at low speeds, and compact design. The rotor and sliding vanes were constructed using hardened alloy steel, which offers high surface hardness, wear resistance, and excellent fatigue life under cyclic loading. The housing was cast in aluminum, providing thermal conductivity and weight reduction, while the bearings and internal components were machined from stainless steel for their anti-corrosive properties and low friction characteristics. The choice of materials ensures long operational life and minimal maintenance even under continuous operation.

4.6.4 High-Pressure Valves

Fig 4: Vane Type Pneumatic Motor [Google]

The pneumatic system employs multiple high-pressure stainless steel (SS) valves, including shut-off valves, flow control valves, and pressure relief valves, capable of shandling up to 300 psi. Stainless steel was chosen due to its corrosion resistance, mechanical durability, and long-term sealing ability. A Pressure Reducing Valve (PRV), constructed from brass and stainless steel, was integrated to regulate the output pressure from the tank to the pneumatic motor. This component plays a critical role in preventing surges and maintaining system stability during operation.

4.6.5 Filter Regulator (FR) Unit

Fig 5: Valve [Google]

To maintain air quality and system reliability, a Filter Regulator (FR) Unit was installed between the tank and the pneumatic motor. This unit serves three functions: it filters impurities and moisture, regulates output pressure, and ensures consistent air delivery to the motor. The body of the FR unit is composed of high-density polymer with internal stainless-steel mesh filters and precision control dials. Its adjustable nature allows operators to fine-tune airflow depending on terrain, load, and desired performance, directly impacting motor efficiency and responsiveness.

Fig 6: Filter Regulator Unit [Google]

4.6.6 Pneumatic Hoses

The air transport system relies on reinforced rubber hoses, designed to endure high internal pressures (up to 300 psi) without bulging, rupturing, or degrading. These hoses exhibit high flexibility, allowing for easy routing around the frame, while resisting abrasion, oil, and temperature fluctuations. The inner lining is composed of synthetic rubber compatible with compressed air, and the outer sheath is braided for additional strength. This construction ensures minimal pressure drop across the network and prevents air loss.

Fig 7: Hose [Google]

4.6.7 Quick-Connect Couplers

To facilitate ease of assembly, disassembly, and maintenance, quick-connect couplers were used throughout the pneumatic line connections. These couplers were made from high-grade brass with stainless steel sleeves and locking balls, allowing for snap-fit leak-proof connections under pressure. Each coupler is equipped with O-rings and rubber gaskets to ensure a secure seal and minimize pressure loss during operation. Their modularity allows for efficient servicing and component replacement without disrupting the full system.

Fig 8: Coupler [Google]

4.6.8 3/2 Valve

A critical control component, the 3/2 valve (three-port, two-position) is responsible for regulating the direction of airflow into the motor. In one position, it allows compressed air to flow into the pneumatic motor; in the other, it vents residual air from the system. This enables motor control and pressure management, preventing undesired torque buildup or energy wastage. Fabricated from corrosion-resistant stainless steel, the 3/2 valve is designed for quick actuation, high cycle life, and zero leakage under operating pressure, contributing to the bike's efficiency and controllability.

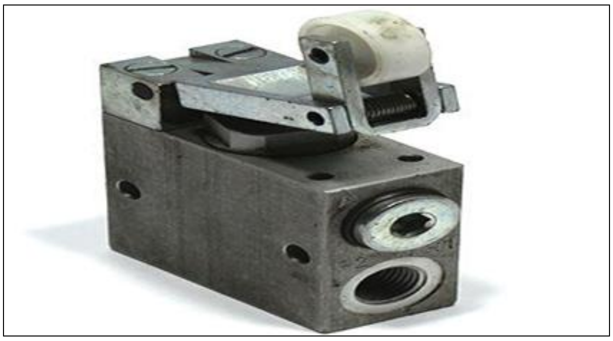

Fig 9: 3/2 Valve [Google]

4.7 Assembly and Testing

Assembly Process

- The Bajaj Caliber 115 chassis was reinforced and adapted for pneumatic integration.
- The air tank was mounted to maintain center balance.
- The vane motor and transmission system were installed using precision brackets.
- All air delivery systems were securely connected using stainless-steel valves, FR units, and couplers.
- A chain drive system was used to transmit motor power to the rear wheel.

Testing Methodology

Tests were conducted on:

- Acceleration and braking
- Air consumption rates
- Range on a single tank
- Motor RPM and torque output
- System leak detection
- Weight balance and rider comfort

Conditions included different terrain types and ambient temperatures. Emergency stop scenarios were evaluated to ensure safety and response time. Adjustments were made based on test feedback to enhance performance and rider ergonomics.

4.8 Final Prototype

The finalized Vane Flow Air Bike prototype represents a fully integrated compressed air-powered two-wheeler with zero emissions and minimal operational costs. Key features include:

- **Chassis**: Modified Bajaj Caliber 115
- **Motor**: Vane-type pneumatic motor (1 HP, max 3,500 RPM)
- **Transmission**: Chain drive with precision sprockets
- **Air System**:

a. 300 psi mild steel air tank
b. Stainless-steel valves
c. Filter Regulator unit
d. Reinforced rubber hoses
e. Brass & SS quick-connect couplers

- **Brakes**: Drum brakes with tested reliability

Performance Highlights

- Smooth and stable acceleration
- Responsive braking system
- Effective power transfer
- Air consumption optimization via FR and valve systems
- Zero emissions and negligible noise

The prototype was subjected to extensive endurance, terrain, and efficiency testing. Leak-proofing, power-to-weight ratio, and ride comfort were prioritized, ensuring the final model meets practical and safety standards for urban use.

Result and Discussion

This chapter presents the findings from the experimental testing of the Vane Flow Air Bike. The primary objective was to evaluate its performance in real-world conditions and compare the results with theoretical predictions. The tests assessed factors such as run time, speed, and efficiency at different pressures, highlighting key areas for improvement.

5.1 Observed Performance Data

5.1.1 Runtime and Wheel Speed Observations

The performance of the bike was tested at varying tank pressures to evaluate how air pressure influences runtime and wheel speed. The results are shown in Table 5.1:

Table 1: Observed Runtime and Wheel Speed

Tank Pressure (bar)	Observed Runtime (seconds)	Wheel Speed (RPM)
4	52	305
10	136	317
12	161	338

The observed data suggests a direct correlation between tank pressure and both runtime and wheel speed. At 12 bars, the system produced a maximum runtime of 161 seconds and a peak wheel speed of 338 RPM.

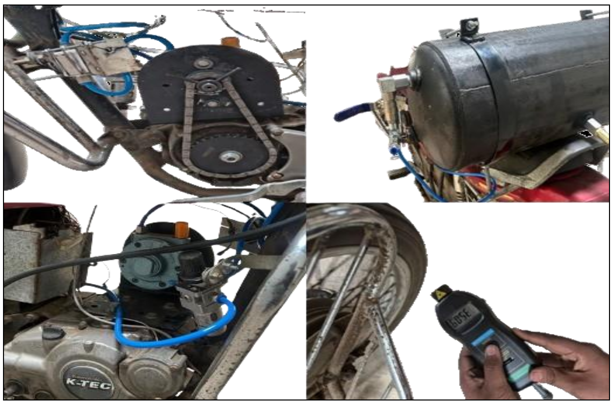

Fig 10: Assembly and Testing

5.1.2 Motor Torque Calculation

The torque generated by the pneumatic motor was derived from the motor power and rotational speed. Given a motor rated at 1 horsepower (746 W) and operating at 3500 RPM, the torque is calculated using the standard relation:

$$T_m = \frac{P \times 9550}{N_m} = \frac{746 \times 9550}{3500} = 2.04\,\text{Nm}$$

Thus, the motor torque is 2.04 Nm.

5.1.3 Torque Transmission Across Stages

The torque at the gearbox input is amplified by the sprocket transmission ratio:

$$R_1 = \frac{\text{Gearbox Sprocket Teeth}}{\text{Motor Sprocket Teeth}} = \frac{32}{12} = 2.67$$

$$T_1 = T_m \times R_1 = 2.04 \times 2.67 = 5.45\,\text{Nm}$$

Torque at the Gearbox Input = 5.45 Nm

5.1.4 Torque Transmission Through Gearbox

The bike utilizes a multi-gear transmission, and torque multiplication varies with each gear ratio. The final drive ratio is fixed at 3.0, and the total gear reduction (R_t) is calculated for each gear stage.

Table 2: Gear Ratios

Gear	Gear Ratio (R_2)
1st	3.8:1
2nd	2.5:1
3rd	1.8:1
4th	1.3:1
5th	1.0:1

The output torque and speed at the wheel are calculated for each gear, assuming a wheel diameter of 0.6 meters.

5.1.5 Torque, Speed, and Range Calculations
The performance characteristics for each gear were calculated as follows:

Table 3: Calculated Torque, Speed, and Range

Gear	Total Ratio (R_t)	Torque at Wheel (Nm)	Wheel RPM (N_x)	Speed (km/h)
1st	30.4	62.1	115	13.0
2nd	20.0	40.9	175	20.0
3rd	14.4	29.4	243	27.7
4th	10.4	21.4	337	38.5

The theoretical maximum speed is 38.5 km/h in 4th gear. Beyond this, increased gearing yields diminishing returns due to limitations in motor torque.

5.2 Air Consumption and Range Calculation
5.2.1 Available Air Volume
To estimate usable air, the total volume of compressed air at atmospheric conditions was computed:

$$V_a = V \times (P_{gauge} + P_{atm}) = 0.04 \times (1.2 + 0.1) = 0.052\ \text{m}^3$$

$$V_a = 0.052 \times 35.314 = 1.836\ \text{ft}^3$$

Available Air Volume = 1.836 ft³

5.2.2 Time to Empty the Tank
Assuming an air consumption rate of 30 CFM (cubic feet per minute):

$$t = \frac{1.836}{30} = 0.0612\ \text{hours} = 3.67\ \text{minutes}$$

Estimated Runtime = 3.67 minutes

5.2.3 Range Calculation
The estimated range is based on the product of speed and runtime:

$$\text{Range} = \text{Speed} \times \text{Time} = 38.5 \times 0.0612 = 2.4\ \text{km}$$

Estimated Maximum Range = 2.4 km (in 4th gear, at 12 bar)

5.3 Observed vs Theoretical Performance Comparison
Theoretical range values were compared to actual observations at 10 and 12 bar pressures across various gears:

Table 4: Observed vs Theoretical Range Comparison

Gear	Theoretical Range (km) @12 Bar	Observed Range (km) @12 Bar	Theoretical Range (km) @10 Bar	Observed Range (km) @10 Bar
1st	0.80	0.49	0.67	0.42
2nd	1.04	0.76	0.87	0.64
3rd	1.44	1.05	1.20	0.89
4th	2.40	1.46	2.00	1.23

The observed range consistently falls short of theoretical predictions, largely due to mechanical losses, air leakage, flow inefficiencies, and variable terrain resistance encountered during field testing.

Conclusion
The *Vane Flow Air Bike* project effectively demonstrates the feasibility of using compressed air propulsion as a sustainable and environmentally friendly alternative to conventional fuel-powered two-wheelers. The research and experimental validation underscore the potential of pneumatic systems to significantly reduce carbon emissions and dependence on fossil fuels.

The prototype achieved a maximum speed of 38.5 km/h, a wheel torque of 62.13 Nm, and an effective range of 2.4 km at an operating pressure of 12 bar. These performance metrics validate the system's operational capabilities for short-distance urban commuting. The vehicle performed efficiently under low to moderate loads, offering smooth acceleration and stable control.

However, certain limitations were observed, notably in terms of range and energy retention, primarily due to limited air storage capacity, mechanical inefficiencies, and air leakage. While the prototype confirms the foundational viability of compressed air propulsion, further enhancements in design and integration are essential for large-scale implementation and commercial viability. Overall, this study contributes meaningfully to the pursuit of clean transportation technologies, affirming compressed air as a promising energy vector in the evolving landscape of sustainable mobility.

Future Scope
- Develop high-pressure and larger-capacity air tanks to extend the vehicle's range.
- Improve valve design, airflow regulation, and sealing methods to reduce air losses.
- Use lightweight materials and advanced gearing to enhance performance and reduce energy loss.
- Integrate electric assist systems with pneumatic propulsion for hybrid functionality.
- Add digital dashboards with real-time monitoring of pressure, speed, and air consumption.
- Optimize design with aerodynamic structures for better mileage and handling.
- Research scalable and cost-effective manufacturing processes for commercial viability.

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