Integration of Diffuser Augmented Wind Turbine on Automobiles for Power Generation: A Novel Approach towards Sustainable Mobility

Submitted By

Naimur Rahaman Naim

190012101

Md. Minhazul Islam

190012133

Supervised By

Prof.Dr. Md. Anayet Ullah Patwari

A Thesis submitted in partial fulfillment of the requirement for the degree of Bachelor of Science in Industrial & Production Engineering

Department of Mechanical and Production Engineering (MPE)

Islamic University of Technology (IUT)

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Candidate's Declaration

This is to certify that the work presented in this thesis, titled, "**Integration of Diffuser Augmented Wind Turbine on Automobiles for Power Generation: A Novel Approach towards Sustainable Mobility**", is the outcome of the investigation and research carried out by me under the supervision of PROF. DR. MD. ANAYET ULLAH PATWARI, Professor, MPE department, IUT.

It is also declared that neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

Naimur Rahaman Naim

Student No: 190012101

MD. Minhazul Islam

Student No: 190012133

Recommendation of the Thesis Supervisors

The thesis titled “Integration of Diffuser Augmented Wind Turbine on Automobiles for Power Generation: A Novel Approach towards Sustainable Mobility” submitted by NAIMUR RAHAMAN NAIM, Student No: 190012101 and MD. MINHAZUL ISLAM, Student No: 190012133 have been accepted as satisfactory in partial fulfillment of the requirements for the degree of B.Sc. in Industrial & Production Engineering **on 7th June, 2024.**

Prof.Dr. Md. Anayet Ullah Patwari (Supervisor)

Professor

MPE Dept., IUT, Board Bazar, Gazipur-1704, Bangladesh.

CO-PO Mapping of ME 4800 -Theis and Project

COs	Course Outcomes (CO) Statement	(PO)	Addressed by	
CO1	Discover and Locate research problems and illustrate them via figures/tables or projections/ideas through field visit and literature review and determine/Setting aim and objectives of the project/work/research in specific, measurable, achievable, realistic and timeframe manner.	**PO2**	Thesis Book	✔
			Performance by research	✔
			Presentation and soft skill	
CO2	Design research solutions of the problems towards achieving the objectives and its application. Design systems, components or processes that meets related needs in the field of mechanical engineering	**PO3**	Thesis Book	✔
			Performance by research	
			Presentation and soft skill	
CO3	Review, debate, compare and contrast the relevant literature contents. Relevance of this research/study. Methods, tools, and techniques used by past researchers and justification of use of them in this work.	**PO4**	Thesis Book	✔
			Performance by research	
			Presentation and soft skill	
CO4	Analyse data and exhibit results using tables, diagrams, graphs with their interpretation. Investigate the designed solutions to solve the problems through case study/survey study/experimentation/simulation using modern tools and techniques.	**PO5**	Thesis Book	✔
			Performance by research	✔
			Presentation and soft skill	✔
CO5	Apply outcome of the study to assess societal, health, safety, legal and cultural issue and consequent possibilities relevant to mechanical engineering practice.	**PO6**	Thesis Book	
			Performance by research	
			Presentation and soft skill	
CO6	Relate the solution/s to objectives of the research/work for improving desired performances including economic, social and environmental benefits.	**PO7**	Thesis Book	✔
			Performance by research	
			Presentation and soft skill	
CO7	Apply moral values and research/professional ethics throughout the work, and justify to genuine referencing on sources, and demonstration of own contribution.	**PO8**	Thesis Book	✔
			Performance by research	
			Presentation and soft skill	
CO8	Perform own self and manage group activities from the beginning to the end of the research/work as a quality work.	**PO9**	Thesis Book	
			Performance by research	✔
			Presentation and soft skill	
CO9	Compile and arrange the work outputs, write the report/thesis, a sample journal paper, and present the work to wider audience using modern communication tools and techniques.	**PO10**	Thesis Book	
			Performance by research	
			Presentation and soft skill	
CO10	Organize and control cost and time of the work/project/research and coordinate them until the end of it.	**PO11**	Thesis Book	
			Performance by research	
			Presentation and soft skill	
CO11	Recognize the necessity of life-long learning in career development in dynamic real-world situations from the experience of completing this project.	**PO12**	Thesis Book	
			Performance by research	✔
			Presentation and soft skill	

Student Name /ID:

Signature of the Supervisor : ………………………….

1. Naimur Rahaman Naim/190012101

Name of the Supervisor: Prof.Dr. Md. Anayet Ullah Patwari

2. Md. Minhazul Islam /190012133

K-P-A Mapping of ME 4800 -Theis and Project

COs	POs	Related Ks								Related Ps							Related As				
		K1	K2	K3	K4	K5	K6	K7	K8	P1	P2	P3	P4	P5	P6	P7	A1	A2	A3	A4	A5
CO1	PO2			✓						✓											
CO2	PO3					✓				✓											
CO3	PO4								✓	✓							✓	✓			
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CO8	PO9																				
CO9	PO10																				
CO10	PO11																				
CO11	PO12																				

Student Name /ID:

1. Naimur Rahaman Naim /190012101
2. Md. Minhazul Islam /190012133

Signature of the Supervisor: ……………………………

Name of the Supervisor: Prof.Dr. Md. Anayet Ullah Patwari

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ABSTRACT

Wind energy, a promising form of renewable energy, has evolved from basic windmills to complex wind turbines, playing a significant role in global energy supply. Innovations in wind turbine technology have led to exploring new applications beyond stationary setups. This thesis investigates the integration of Diffuser Augmented Wind Turbines (DAWTs) with mobile vehicles, focusing on designing, optimizing, and integrating a DAWT system on an auto rickshaw.

The development of wind turbine technology has progressed from harnessing kinetic energy for mechanical tasks to advanced designs like horizontal axis wind turbines (HAWTs), which maximize efficiency and scalability. The global shift towards renewable energy has led to the creation of smaller, adaptable turbines suitable for urban environments. Integrating wind turbines into vehicles leverages the wind experienced by moving vehicles to generate electricity, offering a novel approach to renewable energy. This is particularly appealing for auto rickshaws, common in urban areas with substantial wind exposure. However, challenges include optimizing aerodynamic efficiency, ensuring structural stability, and assessing impacts on vehicle performance.

This thesis addresses these challenges through comprehensive research on a DAWT system for auto rickshaws. It includes literature review, theoretical analysis, and empirical validation. The study highlights the benefits of DAWTs, which use diffusers to increase wind speed through the rotor, enhancing energy capture efficiency beyond traditional limits.

Precision CAD tools were used to design turbine blades and diffuser shells, focusing on aerodynamic performance. The designs were refined through Computational Fluid Dynamics (CFD) simulations to optimize models. Calibration of a custom anemometer ensured accurate wind velocity measurements, aided by IoT technology for real-time data collection.

Integrating the DAWT system into the auto rickshaw required careful consideration of aerodynamics and structural integrity. CFD models evaluated the turbine's impact on vehicle performance, and experimental tests validated the results. Findings indicate potential improvements in energy collection efficiency, suggesting significant implications for urban portable wind energy solutions. The study identifies areas for further design enhancements and adds to the knowledge base of sustainable energy solutions.

This research underscores the potential of combining renewable energy technology with transportation, proposing vehicles as mobile power generators. The study has practical implications for reducing carbon footprints and enhancing energy security in urban areas. By addressing aerodynamic, structural, and performance challenges, this thesis contributes to the development of mobile wind energy applications and supports the global transition to cleaner energy systems.

CHAPTER 1

INTRODUCTION

Wind energy, an ancient method of utilizing natural power, has a long and storied past that can be traced back to early human civilizations. Windmills, which were first utilized in Persia and China more than a millennium ago, were largely employed for mechanical functions like grinding grain and pumping water. These initial modifications established the foundation for the notable progress that would ensue, propelled by the unwavering quest of energy sources that are both more efficient and sustainable. With the advent of industrialization, the emphasis on wind energy shifted from mechanical to electrical power generation, giving rise to the modern wind turbine.

In the late 19th century, the first wind turbines specifically built for energy generation were developed. The concept of harnessing wind energy to generate electricity was proposed by pioneering inventors such as Charles Brush and Poul la Cour. The wind turbine developed by Brush in 1888 was a 12 kW device with a rotor diameter of 17 meters. It produced direct current electricity. Poul la Cour conducted tests in Denmark that significantly improved wind turbine technology. His research specifically concentrated on the generation of alternating current and had a profound impact on the development of future designs.

The advancement of wind turbines gained momentum in the 20th century, namely with the implementation of horizontal axis wind turbines (HAWTs). These turbines, which have blades that rotate along a horizontal axis, have been found to be more efficient and capable of being scaled up in size compared to vertical axis wind turbines (VAWTs). The oil crisis in the 1970s prompted substantial investments in wind energy research, resulting in technological progress that enhanced the efficiency, dependability, and economic feasibility of wind turbines. Wind turbines had become a fundamental element of global renewable energy initiatives by the end of the century.

Currently, wind energy plays a considerable role in the global energy mix, as huge wind farms produce substantial amounts of electricity. Wind energy offers numerous benefits due to its renewable nature, abundant availability, and environmentally friendly characteristics. It serves as a clean power source that aids in mitigating greenhouse gas emissions and decreasing dependence on fossil fuels. Modern wind turbines are advanced and refined devices, honed via extensive research and development over many years. Their purpose is to maximize the extraction of kinetic energy from the wind, which is then converted into mechanical energy and subsequently transformed into electrical energy using a generator.

Exploration of applications outside standard static settings has been driven by the search for innovation in wind energy. A new method involves combining wind turbines with moving automobiles, utilizing the vehicle's encounter with the relative wind speed to produce electricity. This notion is especially fascinating for urban locations, where vehicles such as auto rickshaws are widespread and have the potential to utilize wind energy while in motion. The concept of generating wind energy by mobile means poses distinct challenges and possibilities, necessitating meticulous examination of aerodynamic efficacy, structural integrity, and the influence on vehicle functionality.

The integration of Diffuser Augmented Wind Turbines (DAWTs) with moving vehicles is a relatively unexplored and innovative application. Directly driven wind turbines (DAWTs) employ a diffuser to amplify the velocity of the wind passing through the rotor. This results in a higher efficiency of energy collection compared to traditional wind turbines, surpassing the Betz limit. This method has the ability to enhance the efficiency of wind turbines in situations with low wind speeds. As a result, it is well-suited for urban environments where wind speeds tend to fluctuate and are typically lower than in open rural settings.

The investigation of DAWTs has demonstrated encouraging outcomes in fixed applications. Research has shown that incorporating a diffuser into a wind turbine can greatly enhance its power generation capacity. Nevertheless, the incorporation of DAWTs with mobile vehicles presents other intricacies. Thorough analysis of the aerodynamic interactions between the turbine and the vehicle is necessary to guarantee that the placement of the turbine does not have a negative impact on the vehicle's stability or fuel efficiency. Furthermore, the structural design must consider the dynamic forces encountered during movement.

Computational technologies, specifically Computational Fluid Dynamics (CFD) simulations, have played a crucial role in the progress of wind turbine technology.

Computational Fluid Dynamics (CFD) enables researchers to simulate and examine the movement of air around turbine blades and diffusers, offering in-depth understanding of aerodynamic efficiency. Researchers can enhance turbine efficiency and performance by conducting simulations of various design configurations and operating circumstances. Although CFD simulations offer useful theoretical insights, experimental validation is essential. Empirical data obtained from actual tests in real-world conditions are essential to validate and improve simulation models, guaranteeing their accurate representation of the intricate dynamics of wind energy systems.

Prior studies on transportable wind energy solutions have predominantly concentrated on theoretical frameworks and prototypes of limited scale. Studies have examined the possibility of combining wind turbines with boats and other maritime vessels to utilize the wind speed generated by the vessel's movement for electricity production. These studies emphasize the promise of mobile wind energy systems, but also emphasize the necessity for additional study on land-based applications, such as the integration of wind turbines with vehicles like auto rickshaws.

The auto rickshaw, a prevalent means of transportation in numerous urban regions globally, offers a distinctive prospect for generating mobile wind energy. These cars often encounter strong gusts of wind when driving in urban areas, which makes them ideal for incorporating wind turbines. Nevertheless, the actual possibility and efficiency of combining these elements rely on several aspects, such as the aerodynamic configuration of the turbine, the structural integrity of the vehicle, and the influence on fuel economy and overall functionality.

The objective of my thesis is to tackle these problems by examining the design, integration, and optimization of a DAWT system installed on an auto rickshaw. This study commences with a comprehensive examination of existing literature to determine the theoretical foundations and current deficiencies in the field of mobile wind energy applications. The paper emphasizes the potential advantages of Distributed Acoustic Wave Transducers (DAWTs) and the difficulties linked to their incorporation into mobile vehicles. The turbine blades and diffuser shells are intricately developed using sophisticated CAD tools to optimize aerodynamic performance. The blade design prioritizes the optimization of airfoil profiles, chord lengths, and twist angles, while the diffuser shell is designed to provide a low-pressure area that increases the speed of wind flow through the turbine.

Computational Fluid Dynamics (CFD) simulations are performed to examine the aerodynamic characteristics of the designed components and their interaction with the auto rickshaw. These simulations offer valuable information on the flow patterns, pressure distributions, and aerodynamic forces, which help in making iterative design improvements. The simulation results are essential for optimizing the designs to ensure that the turbine can effectively harness wind energy while maintaining the vehicle's stability and performance.

An essential component of this study entails the calibration of a specially constructed anemometer to provide precise readings of wind velocity. A miniature wind tunnel, built using rigid paper and a tabletop fan, offers a controlled setting for calibration. The anemometer, when combined with Internet of Things (IoT) technology, allows for the immediate gathering and transfer of data, enabling accurate monitoring of wind speeds and turbine operation. The calibration process entails the comparison of the custom anemometer's measurements with those of a commercially available anemometer. This is done to establish calibration curves that can be used to accurately transform voltage outputs into wind velocity data.

When integrating the DAWT system with the auto rickshaw, it is important to carefully analyze the aerodynamic interactions and structural stability. The CAD models of the auto rickshaw and the turbine are merged to evaluate the influence of the turbine's positioning on the vehicle's performance. Computational Fluid Dynamics (CFD) simulations are crucial for studying these interactions, since they guarantee that the integration of the turbine does not have a negative impact on the stability or fuel efficiency of the vehicle. Experimental experiments are performed to verify the accuracy of the simulation results by measuring wind speeds, rotational speeds, and voltage outputs under different conditions.

The research findings provide valuable insights into the aerodynamic characteristics of the DAWT system and its possible practical uses. The incorporation of the turbine inside the auto rickshaw showcases practical enhancements in energy collection efficiency, indicating that portable wind energy solutions could have a significant impact in urban settings. The study also reveals crucial areas for additional design enhancements and optimizations, thereby contributing to the wider knowledge base of sustainable energy solutions.

Overall, the incorporation of DAWT systems into mobile vehicles signifies a groundbreaking method for harnessing renewable energy. This thesis offers a thorough examination of the design, integration, and optimization of a DAWT system on an auto rickshaw, providing vital insights into the practicality and possibilities of using wind energy on mobile platforms. The research highlights the significant impact of integrating renewable energy technology with transportation systems, which aids in the worldwide shift towards cleaner and more efficient energy solutions. The results of this study not only enhance the comprehension of mobile wind energy systems but also lay the groundwork for future advancements in sustainable energy practices.

1.2 Fundamentals of Wind Turbine

Wind turbines are used to transform the kinetic energy of the wind into mechanical power, producing wind energy, a sustainable resource. Then, this mechanical power can be put to use in a number of ways, such as producing electricity. Many theoretical tenets and design factors influence how effective wind energy systems are.

By using wind turbines, wind energy may be efficiently converted into mechanical power through a complicated process driven by fluid dynamics and aerodynamics. A thorough understanding of the underlying theories that govern the operation of wind turbines is necessary in order to optimize this process. In order to prepare readers for a thorough examination of the ensuing concepts and equations, this part offers a thorough synopsis of the major ideas and mechanisms affecting the functionality and efficiency of wind turbines.

Utilizing revolving blades, wind turbines transform the kinetic energy found in moving air masses into mechanical energy. To maximize the efficiency of energy capture and conversion, these blades' design and functioning are crucial.

Improving turbine performance fundamentally requires an understanding of the wind-turbine blade interaction. The complicated aerodynamic forces involved in this interaction. Lift and drag, in particular, are what control the blades' rotating motion. The drag force acts parallel to the wind flow and resists the lift force, which is created perpendicular to the wind flow and propels the rotation. Improving wind turbine efficiency requires careful design and optimization to balance these factors.

Furthermore, the mechanical and electrical components of the system also play a role in the efficiency of wind energy conversion, in addition to the aerodynamic design. The efficiency of a wind energy system is determined by the generator's capacity to transform mechanical energy into electrical energy, the structural soundness of the turbine, the system's overall dependability, and the amount of maintenance needed.

In addition to these factors, the role of computational tools and experimental validation cannot be overstated. Computational Fluid Dynamics (CFD) simulations provide invaluable insights into the flow patterns and aerodynamic behavior of turbine blades, allowing for iterative design improvements and optimizations. Experimental validation, on the other hand, ensures that the theoretical models and simulations align with real-world performance, providing the necessary feedback for further refinement.

The importance of computational tools and experimental validation cannot be emphasized in addition to these other considerations. Iterative design upgrades and optimizations are made possible by Computational Fluid Dynamics (CFD) simulations, which offer priceless insights into the flow patterns and aerodynamic behavior of turbine blades. Conversely, experimental validation guarantees that the simulations and theoretical models match real-world performance, offering the required feedback for additional improvement.

There are new potential and challenges when wind turbines are integrated with other systems, including moving cars. When mounting a wind turbine atop an auto rickshaw, for example, the aerodynamic interactions between the vehicle and the turbine must be carefully considered. The stability and fuel efficiency of the vehicle are also impacted by this integration, in addition to the turbine's performance.

1.2.1 Different Types of Wind Turbines

Wind turbines are available in many varieties, each specifically intended to capture wind energy in diverse ways and ideal for distinct purposes. Wind turbines are primarily classified based on the orientation of their spinning axis. These encompass horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs). Horizontal-axis wind turbines (HAWTs) are widely prevalent and easily identifiable. They have blades that rotate around a horizontal axis and are usually mounted on tall towers to harness stronger winds found at greater heights. Vertical Axis Wind Turbines (VAWTs) differ from other types of wind turbines in that their blades rotate around a vertical axis. These turbines are commonly employed in metropolitan areas where wind directions tend to be more unpredictable. In addition, specialty turbine designs such as Darrieus and Savonius offer distinct benefits for certain uses, while hybrid and floating wind turbines are advanced inventions that aim to maximize energy capture and increase deployment options.

1.2.1.1 Horizontal-Axis Wind Turbines (HAWT):

Horizontal-Axis Wind Turbines (HAWTs) are the most common form of wind turbines. They are distinguished by their rotor blades moving around a horizontal axis that is parallel to the ground. These turbines are commonly installed on elevated towers to take advantage of the increased wind velocities present at higher altitudes. The blades are designed with an aerodynamic form to optimize lift and minimize drag, resulting in efficient energy conversion. Highly efficient and scalable horizontal axis wind turbines (HAWTs) are extensively utilized in both onshore and offshore wind farms.

Advantages:

➢ Excellent efficiency in absorbing wind power.

➢ widely accepted and utilized technology.

➢ Ideal for massive wind farms.

Disadvantages:

➢ Needs a yaw mechanism to maintain the blades' alignment with the wind.

increased expenses for upkeep and installation.

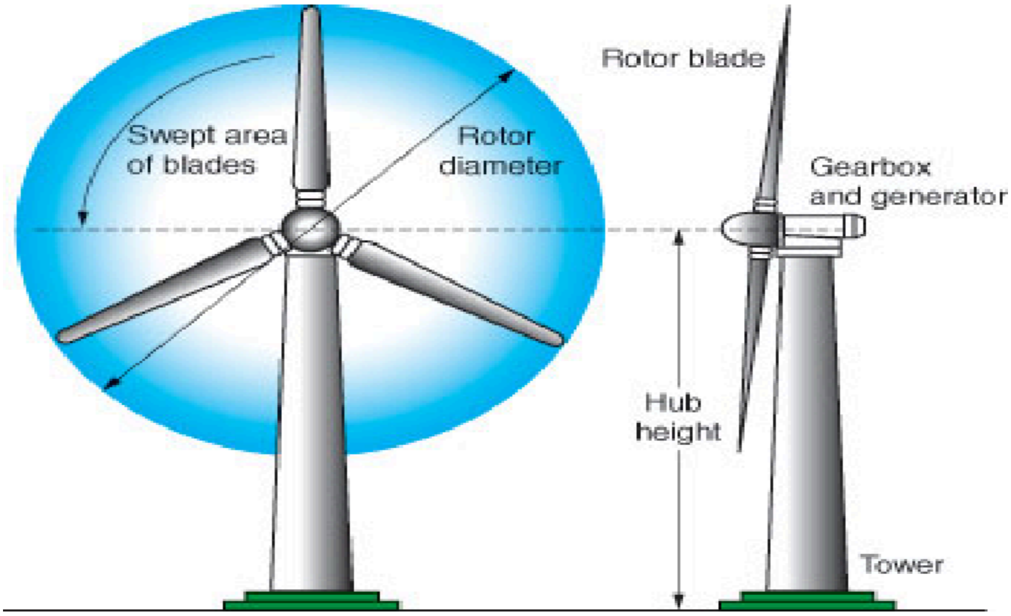

Fig 1.1: Horizontal-Axis Wind Turbines (HAWT) [1]

1.2.1.2 Vertical-Axis Wind Turbines (VAWT):

Vertical-Axis Vertical Axis Wind Turbines (VAWTs) possess a rotational axis that is oriented vertically, which renders them less susceptible to variations in wind direction. This design enables the turbine to harness wind from all directions without requiring yaw devices. Vertical axis wind turbines (VAWTs) are well-suited for metropolitan areas with unpredictable and frequently changing wind directions. Furthermore, their proximity to the ground makes them more convenient to maintain. Nevertheless, Vertical Axis Wind

Turbines (VAWTs) typically exhibit worse efficiency when compared to Horizontal Axis Wind Turbines (HAWTs).

Advantages:

- No requirement for a yaw mechanism because wind can be captured from any direction.
- Reduced center of gravity can ease maintenance and lessen structural stress.
- possibly better suited to erratic wind conditions and urban settings.

Disadvantages:

- Generally speaking, less effective than HAWTs.
- Higher maintenance costs may result from more intricate mechanical designs.

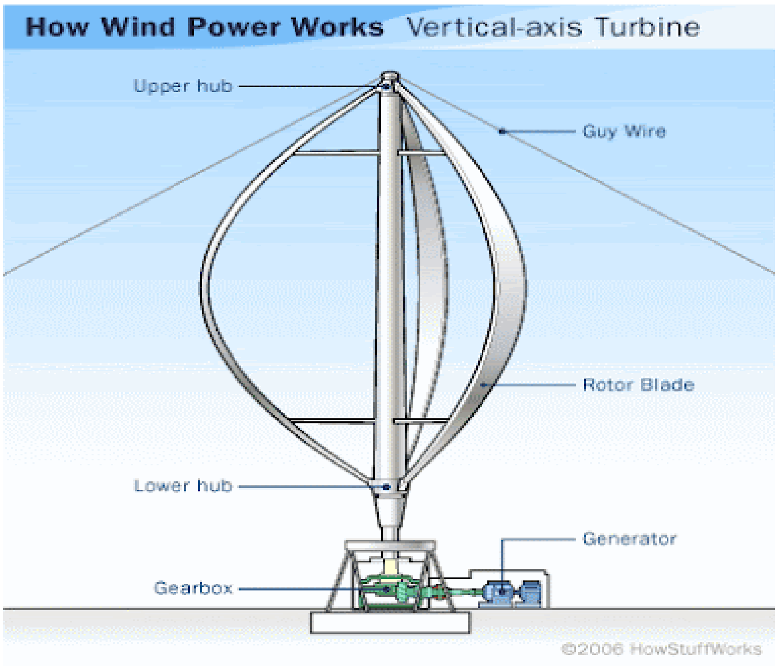

Fig 1.2: Vertical-Axis Wind Turbines (VAWT) [2]

1.2.1.3 Darrieus Wind Turbines:

Darrieus Wind Turbines are a variant of Vertical Axis Wind Turbines (VAWT) distinguished by their curved, blade-like constructions that bear a resemblance to an eggbeater. Georges Darrieus turbines, named after the French engineer, are specifically built to maximize rotational speeds and efficiency by taking advantage of aerodynamic lift. Nevertheless, Darrieus turbines are prone to experiencing structural stress and so necessitate supplementary support structures, rendering them less prevalent compared to HAWTs.

Advantages:

- Includes a quick rotation speed and strong wind performance.

Disadvantages:

- Requires outside power to initiate rotation.
- Mechanical stress can occur in complex blade structures.

Fig 1.3: Darrieus Wind Turbines[3]

1.2.1.4 Savonius Wind Turbines:

Savonius Wind Turbines are a kind of Vertical Axis Wind Turbines (VAWTs) that utilize S-shaped blades to harness wind energy by means of drag, as opposed to lift. Savonius turbines are very efficient at low wind speeds and resistant to turbulent wind conditions.

Advantages:

- Easy to assemble and simple in design.
- Performs well in choppy and low wind environments.

Disadvantages:

- Not as efficient as other varieties.
- Little electricity is generated, which makes it best suited for small-scale uses.

Fig 1.4: Savonius Wind Turbine[4]

1.2.1.5 Hybrid Wind Turbines:

Hybrid Wind Turbines integrate features from both Horizontal Axis Wind Turbines (HAWTs) and Vertical Axis Wind Turbines (VAWTs) in order to maximize energy generation and enhance operational adaptability. These turbines have the ability to adapt their configurations according to wind conditions in order to optimize efficiency. Hybrid designs are now in the experimental stage, but show potential for future applications that require versatility and adaptability.

Advantages:

- ➢ Hybrid turbines can maximize energy extraction under a wider range of circumstances by combining several technologies.
- ➢ They reduce the intermittency problems associated with individual renewable energy sources by providing a more consistent power supply.
- ➢ Hybrid systems make the most of the space that is available, particularly in confined metropolitan areas.

Disadvantages:

- ➢ Adding more than one technology increases the complexity of the system, which raises the initial investment and maintenance needs.
- ➢ Careful design is necessary for hybrid systems to function well and guarantee that all of the parts complement one another.

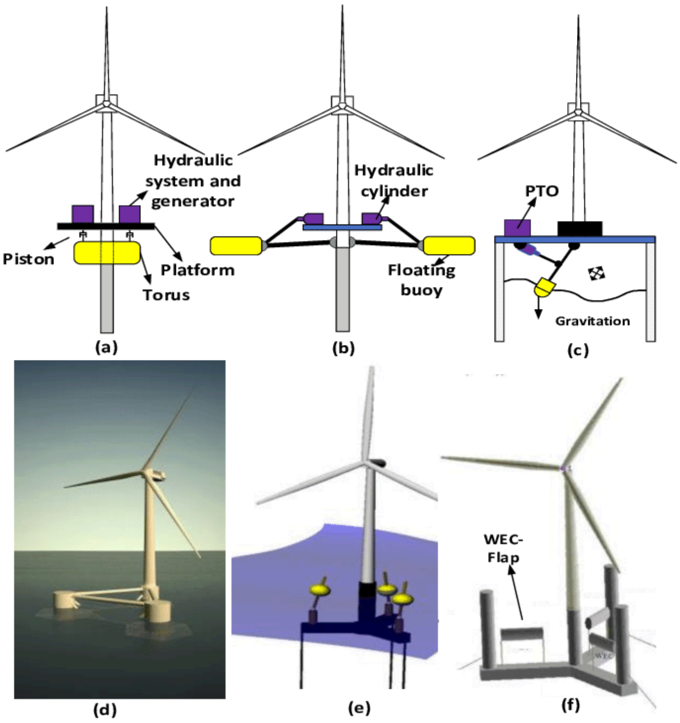

Fig 1.5: Hybrid Wind Turbine [5]

1.2.1.6 Floating Wind Turbines:

Floating Wind Turbines are a notable breakthrough in wind energy technology as they allow for the installation of wind turbines in deep water, where conventional fixed-bottom turbines are not viable. The turbines are installed on buoyant platforms that are secured to the seabed, enabling them to harness powerful and steady winds from offshore locations. Floating wind turbines enhance the capacity for offshore wind farms, hence promoting the diversification and enlargement of renewable energy resources.

Advantages

- Stronger and more reliable wind resources are typically found offshore, which increases energy production.
- They lessen the problems with onshore wind farms' visual impact and conflicts with land use.
- By scaling up to greater sizes, floating turbines can be used to generate renewable energy in broad oceanic expanses.

Disadvantages:

- Because of the complexity of offshore conditions and the requirement for specialized boats and equipment, there are higher initial installation and maintenance expenses.
- Reliability and durability are challenged by the severe sea environment, necessitating strong technical solutions.

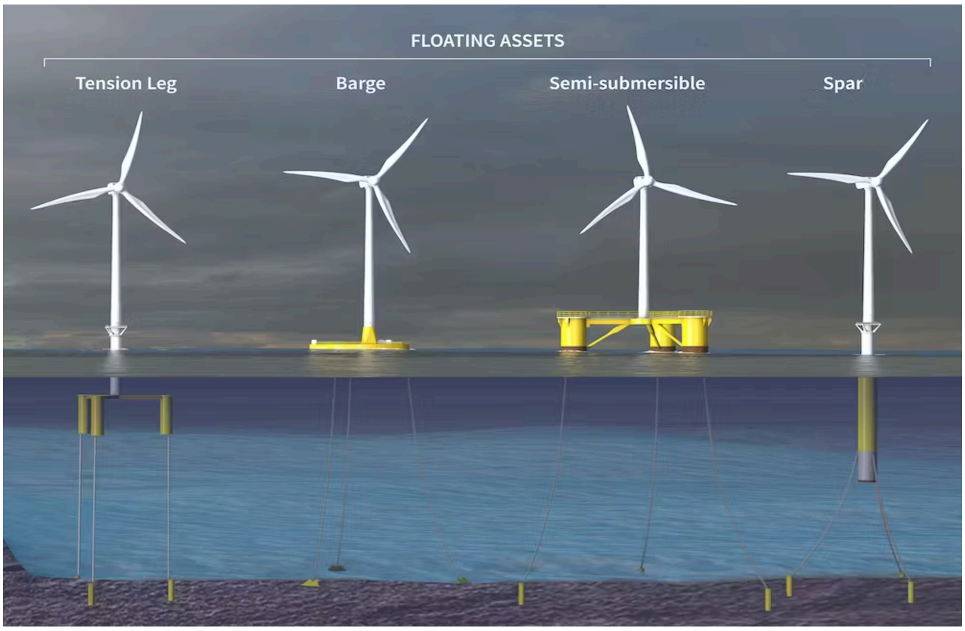

Fig 1.6: Floating Wind Turbine [6]

Different wind turbine types have different benefits and drawbacks, which makes them appropriate for different settings and uses. It is essential to comprehend these distinctions in order to choose the best technology for a certain place and energy requirement.

1.2.2 Principles of Wind Turbines

Aerodynamic principles govern the functioning of wind turbines. A turbine's blades experience lift and drag forces from the wind. The drag force is parallel to the wind direction and adds to resistance, whereas the lift force is perpendicular to the wind direction and is mainly responsible for moving the turbine blades.

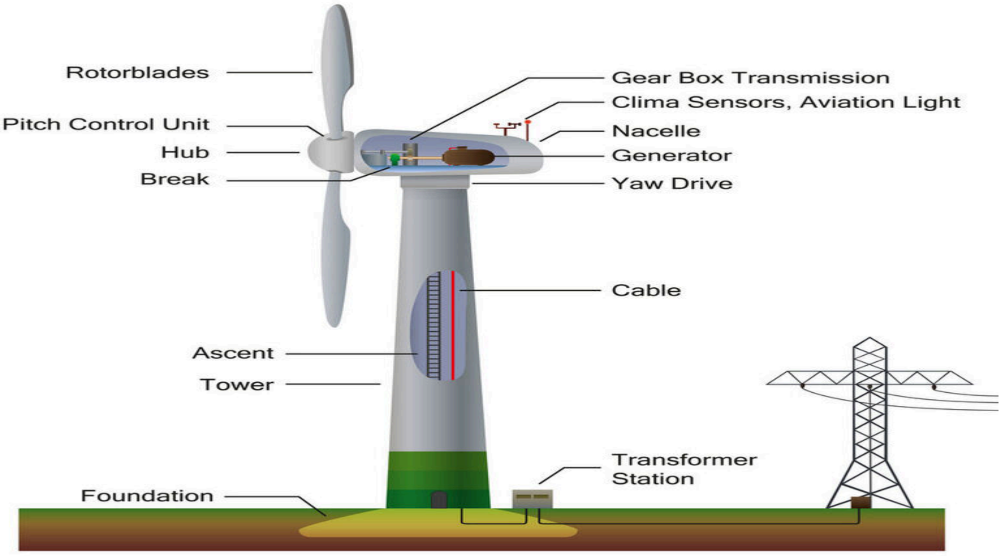

Fig 1.7: Fundamentals of Wind turbines [7]

The power available in the wind that can be captured by a wind turbine is given by:

$$P_{wind}=\frac{1}{2}\rho A V^3 \tag{1.1}$$

where:

- P_{wind} is the power available in the wind (Watts, W)
- ρ is the air density (kg/m^3)
- A is the swept area of the turbine blades (m^2)
- V is the wind speed (m/s)

Betz's Law

Betz's Law provides a theoretical limit on the maximum amount of energy that can be extracted from the wind. According to Betz's Law:

$$C_p = P_{turbine} / P_{wind} \leq 0.593 \tag{1.2}$$

The percentage of the wind's kinetic energy that the wind turbine can transform into mechanical energy is known as the power coefficient, or Cp. The Betz Limit, or theoretical maximum value of Cp, is 0.593. For contemporary wind turbines, the real Cp usually falls between 0.3 and 0.5. The turbine's power output can be stated as follows:

$$P_{\text{turbine}} = C_p \times P_{\text{wind}} = Cp \times \tfrac{1}{2}\,\rho A V^3 \tag{1.3}$$

The basic aerodynamic forces operating on objects traveling through a fluid, such water or air, are lift and drag forces. These forces are essential to comprehending the operation and effectiveness of turbine blades in the setting of wind turbines.

The direction of the airflow is perpendicular to the lift force that is generated. It results from the pressure differential that the shape and angle of attack of the blade create between its top and lower surfaces. The airfoil design for wind turbine blades is maximized lift, which propels the blades' rotation. The lift force is necessary to convert wind energy into rotational energy, which the generator uses to produce electrical power.

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The lift force (F_L) and drag force (F_D) on a blade element are given by:

$$F_L = \tfrac{1}{2}\,\rho\, V^2\, C_L\, A \tag{1.4}$$

$$F_D = \tfrac{1}{2}\,\rho\, V^2\, C_D\, A \tag{1.5}$$

where: C_L and C_D are the lift and drag coefficients, respectively, A is the reference area (it is the chord length of the blade section times the width of the blade section).

The power (P P) generated by the turbine can also be expressed in terms of torque and rotational speed:

$$P = \tau \times \omega \tag{1.6}$$

A variety of mechanical, electrical, and aerodynamic ideas are included in wind turbine principles. It is necessary to comprehend these ideas, together with the important equations, in order to develop, optimize, and put into practice effective wind turbine systems. Through the use of these theoretical underpinnings, engineers may optimize wind energy systems' performance and dependability, thereby aiding in the worldwide shift towards sustainable energy sources.

1.4 Problem Statement

There are numerous major hurdles when it comes to integrating wind turbines onto auto-rickshaws and other compact urban vehicles. These difficulties arise from the special qualities of these vehicles, which can impair the efficiency of traditional wind turbine systems and cause problems including inadequate energy capture and possible stability issues. Furthermore, in urban settings with low wind speeds, ordinary wind turbines frequently have trouble operating properly, requiring specialized solutions to get around these restrictions. By creating a Diffuser Augmented Wind Turbine (DAWT) system especially for auto-rickshaws, this project seeks to overcome these issues. The goal is to maximize energy output while guaranteeing seamless integration and preserving or enhancing the aerodynamic performance of the vehicle. The particular issues and goals of this project are described in detail below:

Factors:

- **Space Restrictions:** There are severe space restrictions when installing wind turbines on auto rickshaws and other small urban vehicles.
- **Wind Variability:** The performance of turbines is impacted by the very varied wind conditions seen in metropolitan areas.
- **Aerodynamic Efficiency**:When wind turbines are added to vehicles, it might be difficult to maintain or increase aerodynamic efficiency.
- **Inadequate Energy Capture:** There may be a reduction in energy capture since current wind turbine systems are not tailored to the special needs of these vehicles.

- **Stability Issues:** The integration of wind turbines on moving vehicles may give rise to potential instability issues.
- **Urban Wind Conditions:** In metropolitan areas with low wind speeds, traditional wind turbines frequently perform poorly, requiring custom solutions.

1.5 OBJECTIVES

- Investigate the aerodynamic performance of a Diffuser Augmented Wind Turbine (DAWT) integrated with an auto rickshaw.
- Design and optimize turbine blades and diffuser shells for enhanced energy capture efficiency.
- Develop and calibrate a custom-built anemometer for accurate wind velocity measurements and validate CFD simulation results with experimental tests.
- Integrate the DAWT system with an auto rickshaw, assessing its impact on vehicle stability and performance.
- Identify key areas for further design improvements and contribute to the broader knowledge.

1.6 Possible Outcomes:

This project, which focuses on developing and putting into practice a Diffuser Augmented Wind Turbine (DAWT) system for auto rickshaws, might lead to the following results:

- **Enhanced Understanding of Aerodynamic Performance:** Acquiring a deeper understanding of the Diffuser Augmented Wind Turbine's (DAWT) aerodynamic behavior and how it interacts with the auto rickshaw body.
- **Optimized Blade and Diffuser Design:** To increase performance and efficiency, optimized designs for the turbine blades and diffuser are developed.
- **Integration Feasibility:** Evaluating how well and practically DAWT systems can be integrated with moving vehicles, including auto rickshaws.
- **Improved Energy Efficiency:** Showcasing possible increases in mobile wind energy systems' energy capture and conversion efficiency.

- ➢ **Empirical Validation of CFD Models:** Using experimental data collection and analysis, empirical validation of CFD models is provided.
- ➢ **Insights into Aerodynamic Drag:** Understanding the effects of the turbine's added aerodynamic drag on the vehicle's overall performance and fuel efficiency.
- ➢ **Real-World Application Data:** Gathering insightful information about the DAWT system's performance in the real world and adding it to the body of knowledge about mobile wind energy applications.
- ➢ **Technology Demonstration:** Highlighting the possibilities for incorporating sustainable energy practices by integrating renewable energy sources with transportation networks.
- ➢ **Identification of Design Improvements:** Using performance analysis and testing data, finding places in need of more design optimizations and enhancements.
- ➢ **Contribution to Sustainable Energy Solutions:** Making a useful and inventive contribution to the creation of renewable energy solutions for mobile and urban applications.

1.7 Thesis Organization

This thesis is meticulously organized into distinct chapters, each contributing to the comprehensive study of integrating Diffuser Augmented Wind Turbines (DAWT) with auto rickshaws. The chapters are structured to provide a logical flow from introduction to conclusion, ensuring a coherent presentation of the research. Following the introduction in **Chapter 1**, which sets the stage by discussing the significance of wind energy, its evolution, and the rationale behind the study.

A comprehensive literature review is presented in **Chapter 2**. This chapter covers existing research on wind turbines, DAWT technology, and related studies, identifying research gaps and highlighting the contributions this study aims to make in the field of mobile wind energy solutions.

Chapter 3 details the methodology, describing the experimental setup, including the design and optimization of turbine blades and diffuser shells. It explains the development and calibration of a custom-built anemometer, the integration of IoT systems for data collection, and the use of CFD simulations to analyze aerodynamic interactions.

The CAD design section in **Chapter 4** provides detailed descriptions and precise measurements of the components designed for this research. It includes visual representations of the blade designs, diffuser shell, and auto rickshaw model, focusing on the iterative process of optimizing these components for maximum efficiency.

Chapter 5 offers an overview of the results and simulations, presenting the results obtained from experimental data and CFD simulations. The analysis covers the power coefficient, turbine efficiency, and the impact of aerodynamic drag on energy dissipation, with comparisons to existing technology and theoretical models.

Finally, **Chapter 6** concludes the thesis by summarizing the key findings and their implications for wind energy. It discusses the potential applications of the developed technology and suggests directions for future research, reflecting on the broader significance of integrating renewable energy with transportation systems. The references section provides a comprehensive list of all the sources cited in the thesis, ensuring proper acknowledgment of existing work in the field.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Research into several aspects of renewable resources, with a concentration on wind energy technology, has increased due to the growing need for sustainable energy alternatives. This evaluation of the literature begins with a thorough investigation of the corpus of information currently available about the design and optimization of diffuser augmented wind turbines (DAWT). In light of the world's environmental problems and the increasing need for clean energy, the goal of this study is to summarize the most important discoveries, approaches, and developments in DAWT technology. Gaps and areas are needed to identify for future study in DAWT design while also providing a strong basis for comprehending the state-of-the-art through an examination of influential works, ongoing discussions, and creative methods.

Researchers, engineers, and stakeholders navigating the ever-changing wind energy market will find great value in the literature review, which is organized to give a thorough overview of DAWT technology from its conception to the most recent developments.

2.2 Literature Review

Here is a brief literature review outlining key studies and research related to small wind turbines, diffuser-augmented systems, and wind energy integration for electric vehicles, with a focus on auto-rickshaws.

Lokesharun et al. uses computational fluid dynamics (CFD) software to analyze and construct a diffuser augmented wind turbine (DAWT). Finding the diffuser's maximum internal velocity and optimizing its design are the goals in order to increase power output. According to the study, when compared to typical wind turbines, a diffuser with flanges and a blade positioned at a particular distance from the diffuser's entrance provides better performance and greater power production.Diffuser Augmented Wind Turbines (DAWTs) have a number of benefits, such as the ability to generate the same amount of power with smaller rotor diameters than traditional horizontal axis wind turbines, lower cut-in wind speeds, lower rotor axial loads, lower levels of turbulence at the rotor plane, lower noise levels, and a decrease in rotor tip losses. DAWTs do have some disadvantages, though, including higher costs for materials, fabrication, transportation, and installation; environmental effects that can affect them; aeroelastic instabilities brought on by flow separation; increased tower structure and top loads; and possible restrictions on installation sites because of their visual impact.[1]

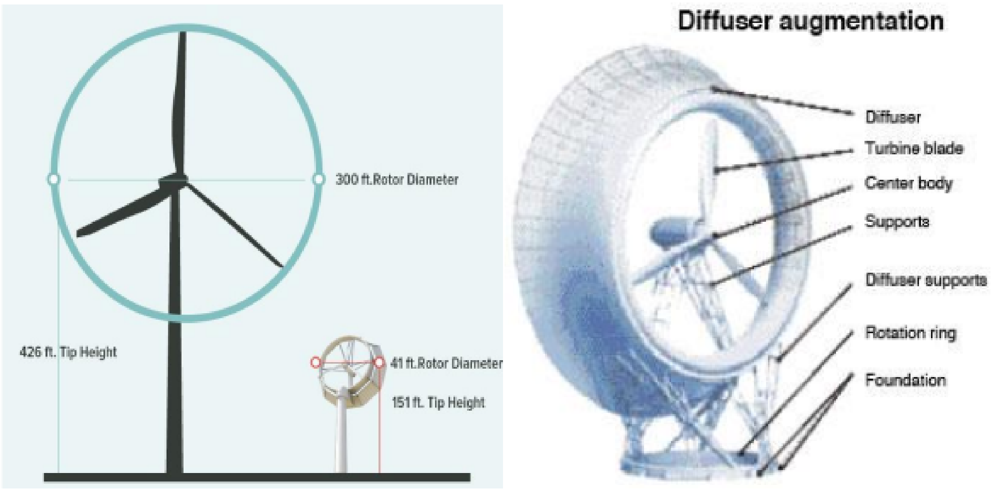


Fig 2.1: DWAT comparison and Parts [8]

Jafari & Kosasih builds a modest commercial wind turbine with a straightforward frustum diffuser shrouding is the subject of a computational fluid dynamics (CFD) simulation research which is presented in this paper. The study's objective is to comprehend how power augmentation is impacted by diffuser length and area ratio. The findings indicate that the diffuser area ratio has a substantial impact on sub-atmospheric back pressure, which is the most important component in power augmentation. The diffuser's flow separation may also lower the total power coefficient, however this may be countered by varying the diffuser's length. Effective frustum diffuser shapes for tiny wind turbines are provided by the study. [2]

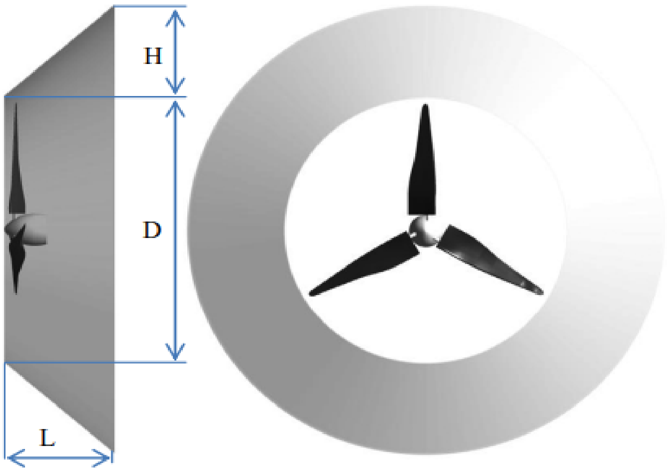
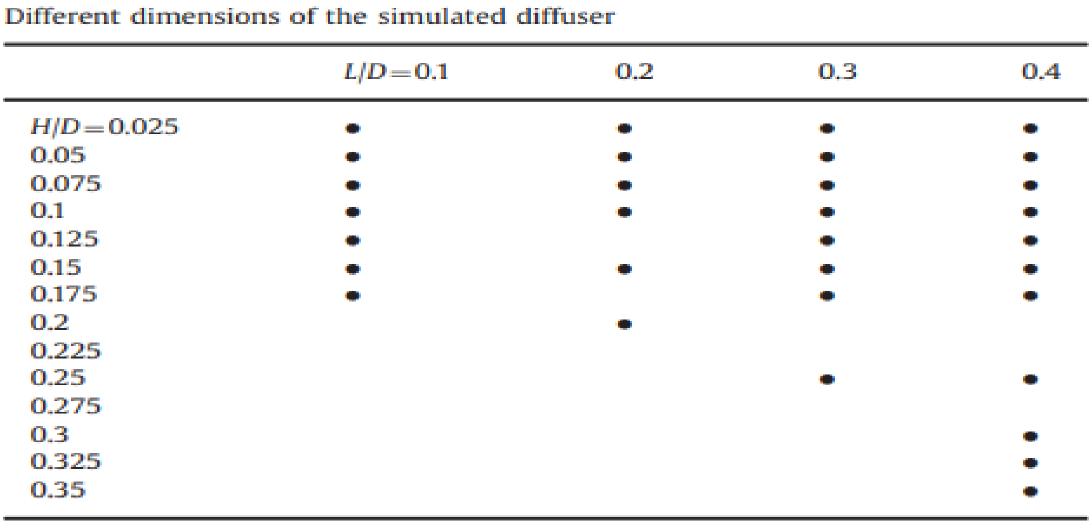


Fig 2.2 :Dimensions of AMPAIR 300 diffuser [9]

Table 2.1: Different dimensions of the simulated diffuser [10]



Different dimensions of the simulated diffuser

	$L/D=0.1$	0.2	0.3	0.4
$H/D=0.025$	●	●	●	●
0.05	●	●	●	●
0.075	●	●	●	●
0.1	●	●	●	●
0.125	●		●	●
0.15	●	●	●	●
0.175	●		●	●
0.2		●		
0.225				
0.25			●	●
0.275				
0.3				●
0.325				●
0.35				●

Chaudhary & Roy covers the design and optimization of a compact wind turbine blade for low wind operation. The turbine's energy absorption mechanism relies heavily on the blade, and the effectiveness of energy absorption is influenced by the blade's design. The main objectives of the study are to pick the tip speed ratio that corresponds to the solidity and to optimize the number of blades. By applying blade element momentum techniques, the power performance of tiny horizontal axis wind turbines is simulated. When designing a blade, a number of parameters are taken into account, including wake, drag coefficient, tip loss, and hub loss. . According to the study, for various tip speed ratios, the maximum power coefficients (Cp) of the three-, five-, and seven-bladed rotors are 0.46, 0.5, and 0.48, respectively.

The study also establishes the ideal chord length and blade twist angle for the most effective blade shape. All things considered, the results indicate that the power coefficient rises until blade number five, after which it falls.[3]

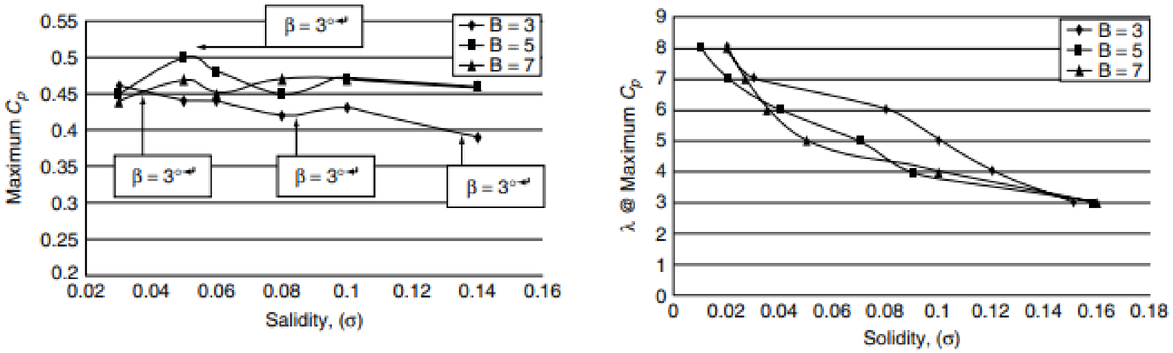


Fig 2.3: Comparison of maximum power coefficient with solidity for blade numbers = 3, 5 and 7[11]

Bussel covers the science of harnessing diffuser experiments and theories to increase wind-generated torque in this article. It looks at the development issues and history of diffuser augmented wind turbines, or DAWTs. The paper also addresses the pressures and velocities inside an empty diffuser and provides a basic momentum theory for DAWTs. The intricacy of pressure and velocity connections inside DAWTs is highlighted in the conclusion, along with the necessity of more study in this field.This article covers the science of using diffuser experiments and hypotheses to improve wind-generated torque. It examines the history and development challenges of diffuser augmented wind turbines, or DAWTs. The study also gives a rudimentary momentum theory for DAWTs and discusses the pressures and velocities within an empty diffuser. The conclusion emphasizes the complexity of pressure and velocity relationships inside DAWTs and calls for more research in this area.[4]

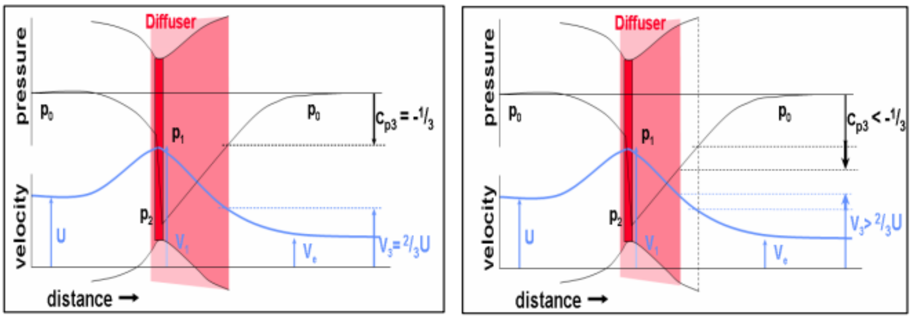


Fig 2.4: Optimal velocity and pressure relations in a DAWT obtained from momentum theory

Left: diffuser without extra backpressure ($\gamma = 1$)

Right: diffuser with extra backpressure ($\gamma > 1$)[12]

Gilbert & Foreman discusses the potential of a diffuser-augmented wind turbine (DAWT) to outperform traditional wind energy conversion systems in terms of power production in the article along with its experimental development. In order to boost the wind energy density at the turbine and produce more mass flow and power output, the DAWT uses a static shroud. The article provides the findings from a series of experiments carried out in a wind tunnel with various diffuser layouts and turbine types. The results of the studies demonstrate that the DAWT system can produce electricity more than four times as much as a conventional wind turbine and more than 3.4 times as much as an ideal wind turbine.
The diffuser-augmented wind turbine (DAWT) system may boost the power production by more than four times when compared to a normal wind turbine, according to experimental testing carried out in a wind tunnel. In comparison to conventional wind energy conversion systems, the DAWT system has the potential to greatly increase power output, according to the findings of testing using different diffuser designs and turbine types.[5]

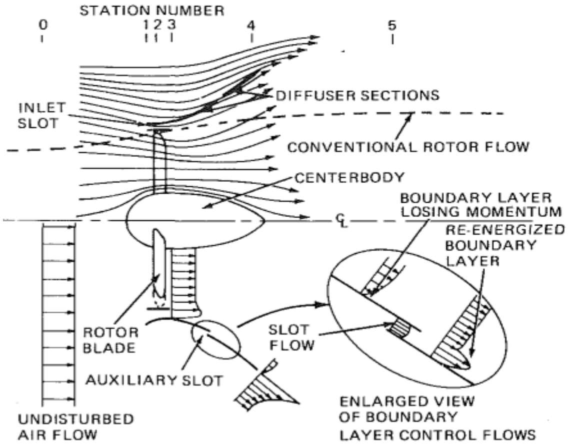
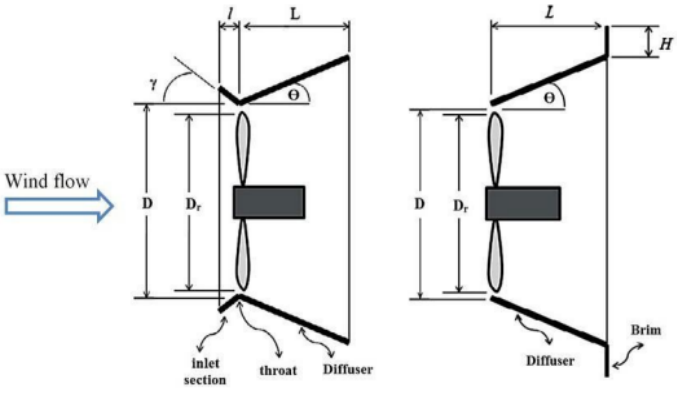


Fig 2.5: Schematic of flow field for baseline DAWT configuration[13]

Alquraishi reviews the idea of a Diffuser Augmented Wind Turbine (DAWT) in this article as a way to increase wind turbine efficiency. Wind power output may be increased by using DAWTs, particularly in metropolitan areas and other places with low wind speeds. The review is on increasing output and improving aerodynamic forces in horizontal axis wind turbines (HAWT). The results emphasize how DAWTs may produce more wind energy and produce less noise.The analysis comes to the conclusion that Diffuser Augmented Wind Turbines, or DAWTs, can greatly boost wind power generation, particularly in cities with low wind rates. It highlights how crucial it is to have the best possible diffuser and shroud design in order to increase power in HAWTs. Using DAWTs also lessens turbine noise and shields the blades from harm.[6]

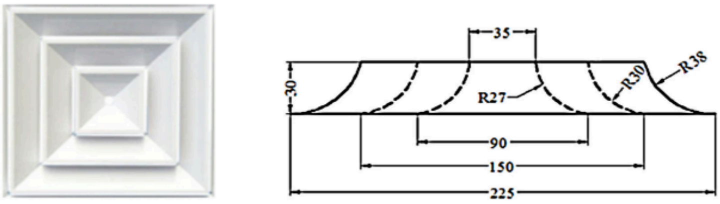


(a)

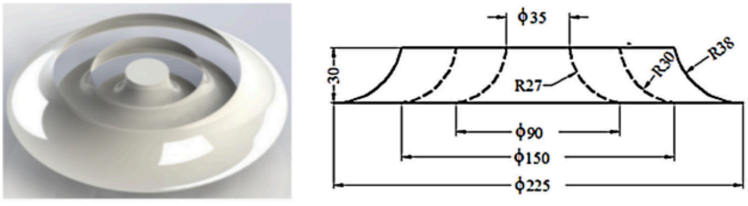
(b)

Fig 2.6: Typical shroud designs for wind turbine: (a) nozzle-diffuser; (b) diffuser-brim shroud[14]

Mohammed uses more straightforward approach for modeling square and circular ceiling diffusers in an effort to speed up simulation. Three distinct turbulence models and experimental data are used to validate the strategy. A streamlined model is created for the diffusers following validation. The article's conclusion is that realistic room airflow models can use this straightforward technique.Regarding accuracy and application, the simplified diffuser modeling approach is equivalent to the fully stated method. According to the study, three distinct turbulence models and experimental data are used to confirm the simplified model's correctness. It is also discovered that the simplified model may be used for realistic room airflow simulations, proving its applicability and feasibility.[7]



Square Diffuser



Round Diffuser

Fig 2.7: Geometry of square and round diffuser [15]

P. D. Clausen & D. H. Wood examines current developments in small wind turbine technology, concentrating on units that can produce up to 50 kW of power. The types of tiny turbines, their distinct aerodynamic properties, and blade manufacturing techniques are covered in the article. It also covers new advancements in the industry, including certification of designs, manufacturing processes for blades, microprocessor controls, and aerodynamics. Two case studies of tiny turbine design are included in the essay, which ends with a review of recent advancements including fatigue testing of blades and new techniques for blade design.Recent advances in the production of blades and aerodynamics have greatly improved tiny turbine technology. The peculiar difficulties faced by tiny turbines, such as their beginning behavior, low-wind-speed performance, and the use of tail fins for yaw control, are now well understood thanks to developments in aerodynamics. More resilient and effective turbine blades have also been developed as a result of advancements in blade production techniques, such as the use of solid lumber, glass-fiber laminated composites and carbon fiber laminated composites. These developments have made it possible for tiny wind turbines to operate more effectively overall and to produce them at lower manufacturing costs.[8]

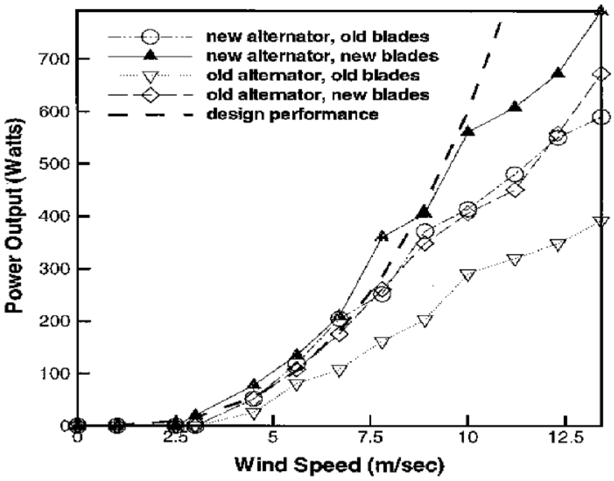


Fig 2.8: Power curve for 600 W turbine [16]

Lipian et al. covers the sensitivity analysis of the brim height and diffuser angle parameters for the design of a 3 kW diffuser augmented wind turbine (DAWT). By encircling the rotor with a duct in the shape of a diffuser, the DAWT wind turbine enhances the amount of power it harvests by 40–50% while also increasing the flow rate through the turbine. The creation of a numerical model and its validation through wind tunnel tests are presented in this article. A sensitivity assessment is then conducted using the numerical model to optimize the diffuser's form. According to the findings, a wind turbine with DAWT technology might produce twice as much electricity as one with a naked rotor.[9]

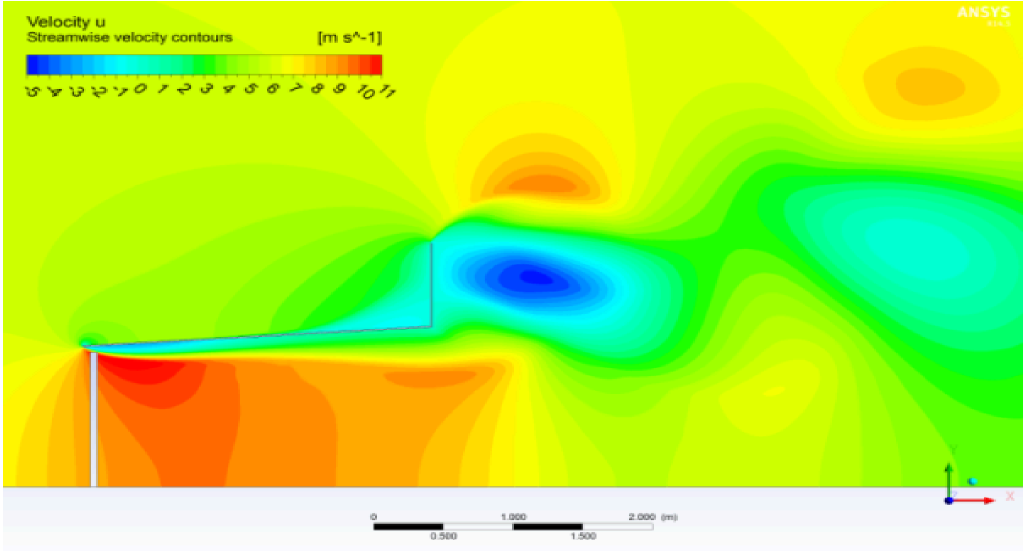


Fig 2.9 :Velocity contour plot of flow through DAWT, D = 2.5 mm, L = D, h = 0.3D, 2α = 8°[17]

Singh & Ahmed covers the design and performance evaluation of a compact wind turbine rotor for low wind speed applications in this article. To enhance performance in low wind situations, the rotor has a low Reynolds number airfoil that has been carefully developed. According to the study, the turbine operated most efficiently at an 18-degree pitch angle, producing a power coefficient of 0.255 at 6 m/s of wind. At the same wind speed, the new 2-bladed rotor generated more electrical power than the standard 3-bladed rotor.In terms of producing electricity, it was discovered that the new 2-bladed rotor performed better than the standard 3-bladed rotor. According to the study, the 2-bladed rotor outperformed the baseline 3-bladed rotor in terms of electrical power production at the same wind speed. To be more precise, the 2-bladed rotor generated a power coefficient of 0.255 at a wind speed of 6 m/s, compared to 0.15 for the 3-bladed rotor that was used as a baseline. This shows that as compared to the standard 3-bladed rotor, the 2-bladed rotor design produced noticeably more electrical output.[10]

Keramat Siavash covers the creation of a compact wind turbine with an adjustable shroud in this article. The diffuser wall aperture may be adjusted thanks to the shroud's two-piece rotating diffuser that is attached to a fixed ring. This mechanism's goal is to regulate the drag forces and speed-up ratio operating on the turbine construction at high wind speeds. Tests of the turbine's performance in a low-speed wind tunnel revealed that the shrouded wind turbine significantly increased rotor speed and power output.By adjusting the diffuser wall aperture, the adjustable shroud modifies the speed-up ratio and drag forces exerted on the turbine structure at high wind speeds. The device is made to control the turbine's performance under various airflow circumstances, which greatly boosts power production and rotor speed.[11]

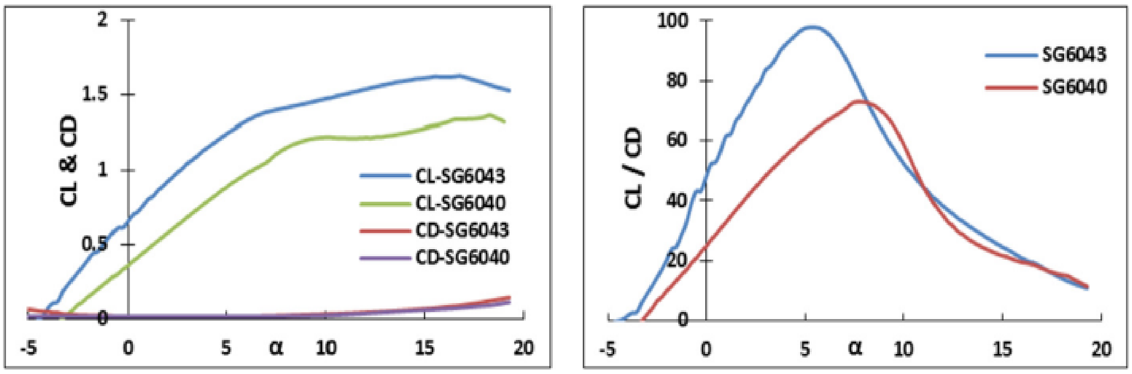


Figure 2.10: SG6040 and SG6043 lift and drag coefficient [18]

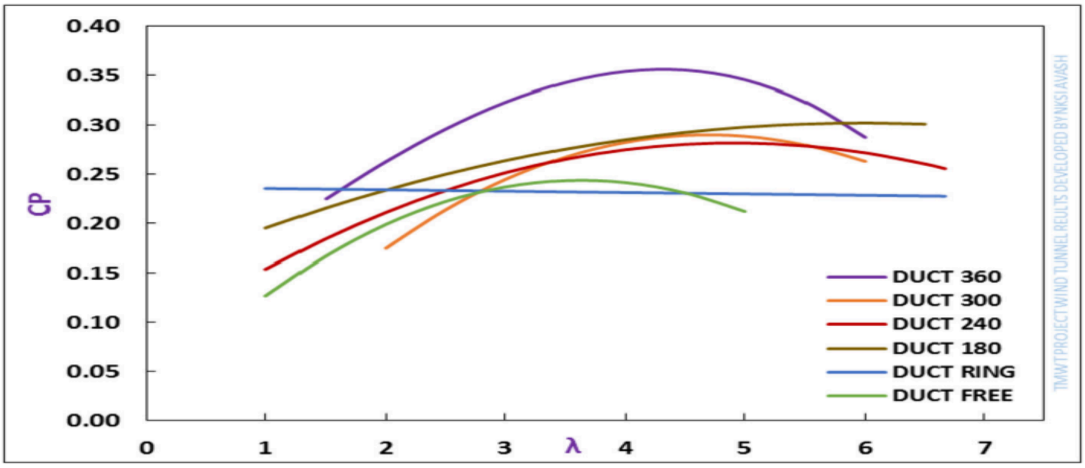
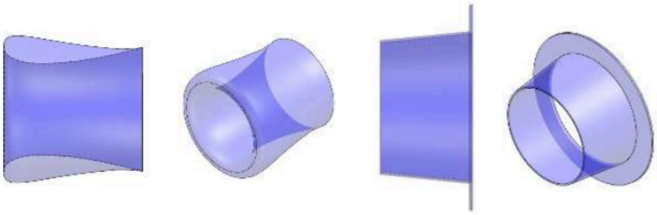
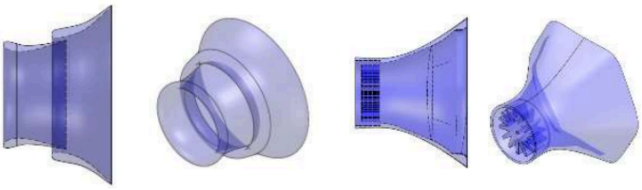


Figure 2.11:Power coefficient vs. blade tip speed ratio [19]

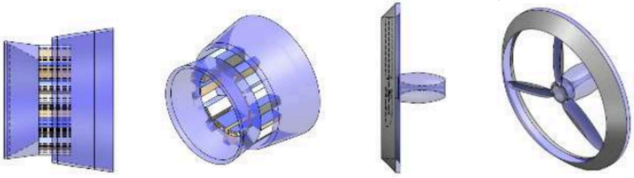
Heriot-Watt Research Portal discusses the optimized type of wind turbines known as diffuser-augmented wind turbines (DAWTs) that uses a diffuser to accelerate and direct air flow onto a wind turbine rotor. As a result, compared to turbines without a diffuser, the RPM and power production are higher. The theory and design of diffusers are examined, along with the application of computational fluid dynamics (CFD) to the development of DAWTs. It also showcases several large-scale, aerial, ground-based, and building-integrated DAWT designs. In order to solve problems such increased diffuser weight, turbine stability, and the impacts of loading and yaw angle, the essay emphasizes the necessity for additional innovation.A key component of the design and operation of diffuser augmented wind turbines (DAWTs) is computational fluid dynamics (CFD). It facilitates comprehension of the properties of airflow, including flow separation, boundary layer effects, turbulent and steady-state flow, and velocity and pressure profiles. Additionally, CFD helps in augmentation parameter assessment, diffuser design optimization, and performance and design prediction.[12]



a) Tne Simple Diffuser b) Diffuser with Brim/Flange



c) Multi-Slot Diffuser d) Vorticity-based Diffuser



e) Mixer-Ejector Diffusers f) Rotating Diffusers

Fig 2.12: Different types of diffuser [20]

Vaz & Wood presents a novel method for optimizing the aerodynamics of wind turbine blades with a diffuser in this article. The study makes use of a straightforward diffuser efficiency model as well as an expansion of the Blade Element Theory. In the presence of a diffuser, the presented algorithm optimizes the distributions of the blade chord and twist angle. The findings demonstrate an enhancement in the turbine rotor geometry's aerodynamic performance, with the blade shape being responsive to the diffuser speed-up ratio. The suggested method is contrasted with the traditional Glauert optimization and published experimental findings, showing superior performance for the rotor created using the suggested optimization process.[13]

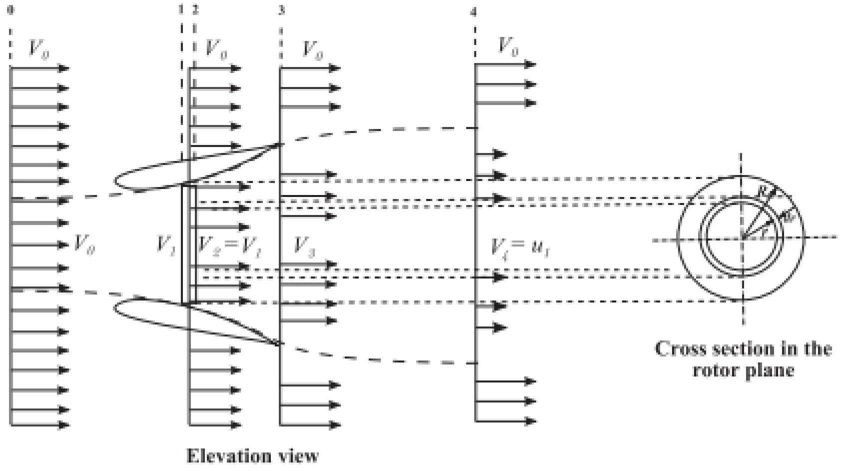


Fig 2.13: Simplified illustration of the velocities at the rotor plane and in the wake [21]

Quartey covers the design of a wind turbine that may be installed on an electric vehicle to produce electricity and charge the batteries while the vehicle is moving. The car's roof, where the air flow is greatest, is where the turbine is mounted. The design makes use of a portable horizontal axis diffuser augmented wind turbine, which has a larger power output than traditional wind turbines. The article also describes how to charge an electric car and the main parts of an electric car's driving system. It offers details on the various kinds of wind turbines and the velocity distribution surrounding a moving vehicle. The wind turbine's main shaft, generator, rotor, main bearing, and safety guards are all part of the suggested design.Utilizing the kinetic energy of the wind while the vehicle is moving, the electric car's wind turbine produces electricity. When the car is moving, the turbine, which is mounted on the roof where air flow is greatest, begins to produce electricity. The batteries may then be continuously charged while the automobile is moving thanks to the generator's electrical connection to the charging system and the transfer of rotational energy from the turbine's rotor.[14]

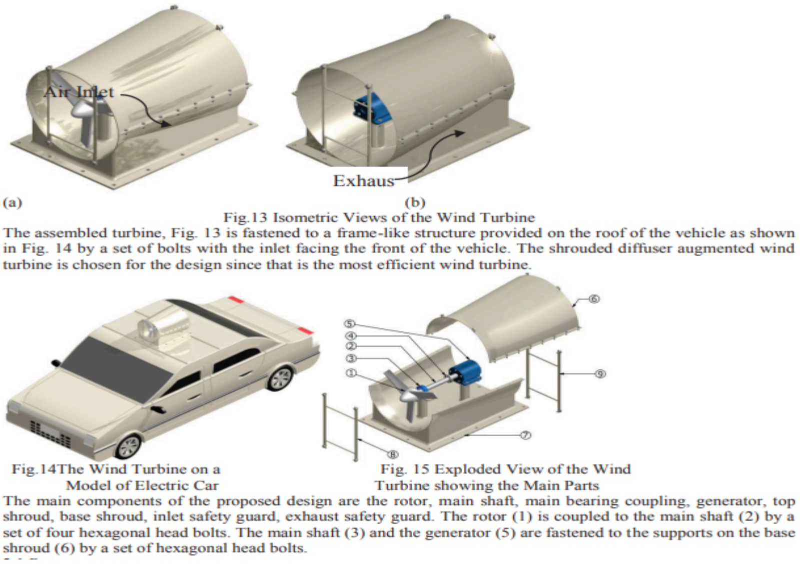


Fig.13 Isometric Views of the Wind Turbine

The assembled turbine, Fig. 13 is fastened to a frame-like structure provided on the roof of the vehicle as shown in Fig. 14 by a set of bolts with the inlet facing the front of the vehicle. The shrouded diffuser augmented wind turbine is chosen for the design since that is the most efficient wind turbine.

Fig.14The Wind Turbine on a Model of Electric Car

Fig. 15 Exploded View of the Wind Turbine showing the Main Parts

The main components of the proposed design are the rotor, main shaft, main bearing coupling, generator, top shroud, base shroud, inlet safety guard, exhaust safety guard. The rotor (1) is coupled to the main shaft (2) by a set of four hexagonal head bolts. The main shaft (3) and the generator (5) are fastened to the supports on the base shroud (6) by a set of hexagonal head bolts.

Fig 2.14: Wind turbine in a car [22]

Battisti covers the usefulness of tiny wind turbines in urban settings. It highlights how crucial it is to have an appropriate control plan for these turbines, particularly in strong, turbulent winds. The article compiles and contrasts information from literary sources, design best practices, and statistics from turbines that are commercially accessible. It draws attention to the connection between rotor inertia and angular acceleration and poses concerns regarding the viability of tracking the ideal operating state continuously. In addition, the paper offers a fresh method for evaluating how well various turbines work at a certain installation location and offers a trustworthy approximation of the energy output depending on the site's time scale and the turbine's reaction time.

These selected studies offer a foundation for understanding the design principles, challenges, and advancements in the areas of small wind turbines, diffuser augmentation, and wind energy integration for electric vehicles, setting the stage for further exploration in the context of auto-rickshaws.The wind turbine's capacity to adjust its angular speed in reaction to abrupt variations in wind velocity is hampered by the rotor's inertia. The longer it takes the turbine to adjust its rotational speed to the varying wind conditions, the greater the rotor inertia. This may make it more difficult for the turbine to react to changing winds, particularly in urban settings where wind potential is low and circumstances change quickly.[15]

P.J. Schubel & R.J. Crossley does a thorough analysis of wind turbine blade design in this article, including factors such as propulsion, theoretical maximum efficiency, practical efficiency, blade design, and blade loads. The article addresses the aerodynamic design concepts for these blades and emphasizes how common horizontal axis rotors are in contemporary wind turbines. It also discusses the aerodynamic, gravitational, centrifugal, gyroscopic, and operating circumstances design stresses on wind turbine blades.Aerodynamic loads, gravitational loads, centrifugal loads, gyroscopic loads, and operational loads are among the various design loads that wind turbine blades encounter. These loads are essential to the blades' structural integrity and functionality.[16]

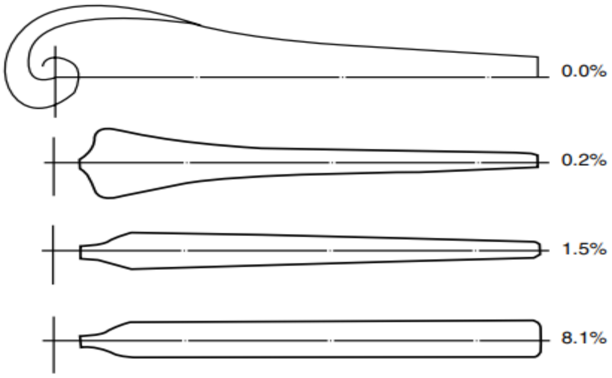


Fig 2.15: Efficiency losses as a result of simplification to ideal chord length [23]

Silva offers a novel method for developing diffuser-augmented hydro turbines (DAHTs) that takes the efficiency of the diffuser into account. According to the research, encircling a turbine with a di\ufb00user can boost its power considerably, perhaps yielding a power coefficient roughly double that of a standard turbine. New formulas for the thrust and axial induction factor based on the momentum theory of the blade elements are proposed in this work. Computational fluid dynamics is used to assess the suggested model and compare it with experimental results. The findings demonstrate that, in comparison to other models found in the literature, the suggested model produces better results and achieves good agreement with the numerical model.[17]

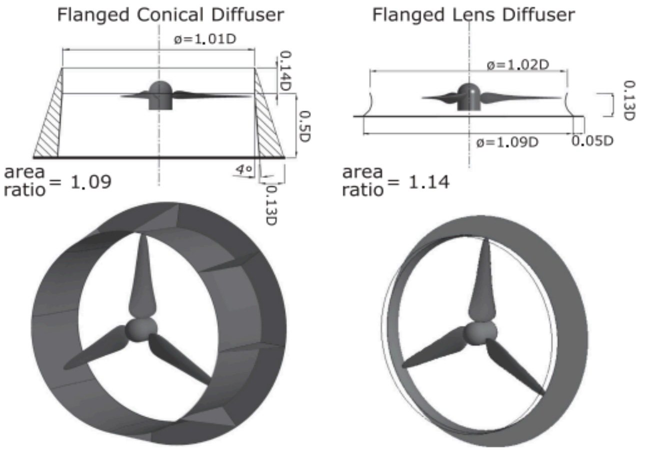


Fig 2.16: Geometrical illustration of FCD and FLD [24].

Polinder shows that the Diffuser Augmented Wind Turbines (DAWTs) are a cutting-edge development in wind energy technology that integrate a diffuser structure around the rotor to improve the performance of conventional wind turbines. By increasing the wind speed entering the rotor, this integration boosts energy production and efficiency. The idea, which has its origins in early research conducted in 1983 by Gilbert and Foreman, makes use of the idea of generating a low-pressure area at the diffuser outlet in order to increase wind flow through the turbine and perhaps surpass the Betz limit of 59.3% efficiency for standard turbines. To maximize aerodynamic performance, a variety of diffuser shapes, such as conical, cylindrical, and trumpet-shaped diffusers, have been investigated. Up to 2.5 times more energy is produced by recent applications in urban and offshore environments than by traditional turbines of the same size.Ongoing research focuses on optimizing designs, cutting prices, and incorporating modern materials despite obstacles including greater beginning costs and structural complexity. With further invention and development, DAWTs have the potential to greatly contribute to sustainable energy solutions, marking a promising advancement in wind energy technology.[18]

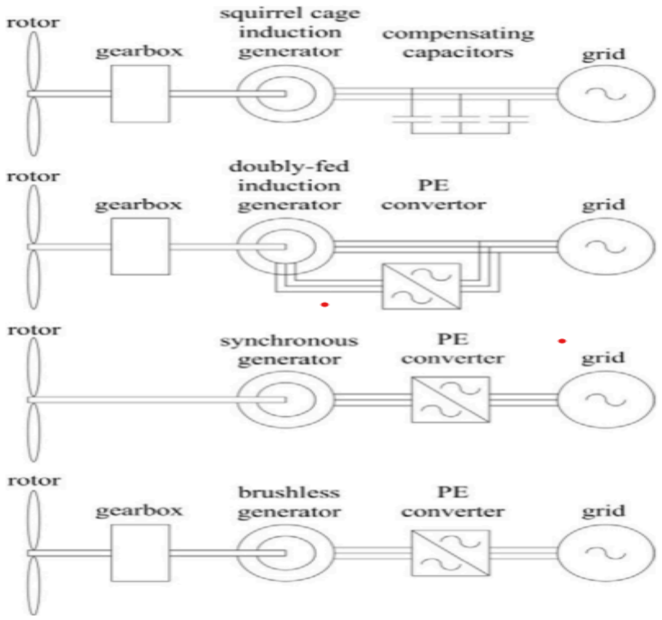


Fig 2.17 ;Four commonly used generator systems [25]

Novaes Menezes shows comprehensive analysis of wind turbine (WT) control systems. In order to maximize efficiency and guarantee the financial viability of wind energy, it highlights the significance of these systems. Pitch control, generator torque control, and grid integration control for frequency regulation are the three primary categories into which WT control is divided in the evaluation. It addresses many approaches within these groups, including sliding mode control, hill-climb search, power signal feedback, optimum torque control, and individual and collective pitch control. Along with these new innovations, the study highlights the uses of smart rotors, LIDAR technology, and Model Predictive Control (MPC).The present evaluation functions as a fundamental source for forthcoming investigations that seek to enhance wind turbine technology and foster sustainable energy generation.[19]

M. Balat gives an overview of current wind turbine technology and demonstrates the noteworthy progress made in wind energy, which is a clean, renewable energy source that produces almost no pollution. The study goes into detail on the development and efficiency gains made to wind turbines, including both the vertical-axis (VAWT) and horizontal-axis (HAWT) types. Thanks to developments in electronics, engineering, and materials science, modern wind turbines are said to be incredibly dependable, efficient, and economical. The focus of the essay is on how control systems and aerodynamic blade design may maximize energy harvesting while lowering expenses. Wind energy is positioned as a major actor in the shift to sustainable energy systems due to the increase of wind energy capacity worldwide and the financial advantages of wind power over fossil fuels.[20]

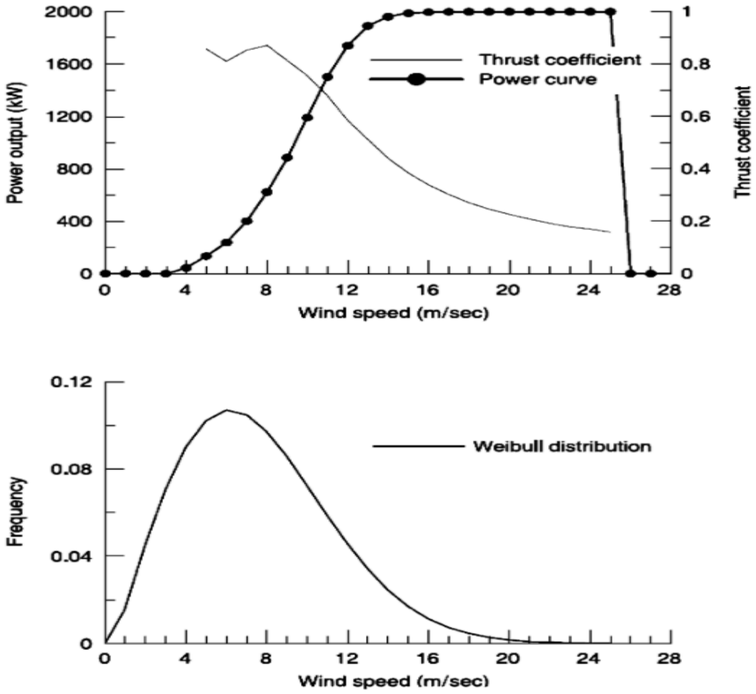


Fig 2.18: A sample Weibull distribution with a scale value of 8.0 m/sec & a shape parameter of 2.0 [26]

Eriksson discusses on Darrieus Vertical Axis Wind Turbines (VAWTs), H-Rotor VAWTs, and Horizontal Axis Wind Turbines (HAWTs) are the three primary types of wind turbines that are evaluated and compared in this article. Structural dynamics, control systems, production, maintenance, and electrical equipment. Important conclusions show that although HAWTs are more well known and used, VAWTs—specifically, the Darrieus and H-Rotor types—offer clear benefits in some situations. These include reduced noise levels, easier construction and maintenance, and the capacity to function well in windy situations even when yaw mechanisms are not required. A case study comparing 500 kW turbines of each type is also shown in the report, demonstrating that VAWTs can be competitive alternatives to HAWTs, particularly in settings with varying wind direction. [21]

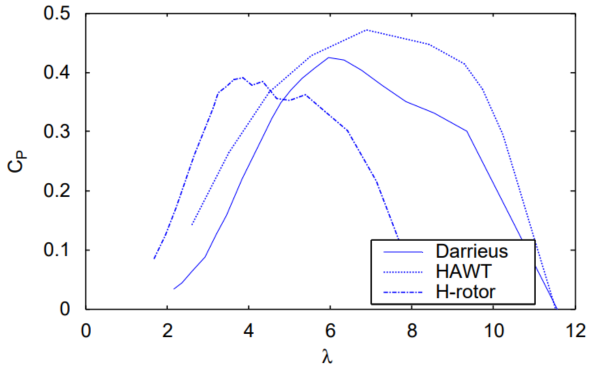


Fig 2.19: Comparison of Darrieus VAWTs, H-Rotor VAWTs and HAWT's data [27]

2.3 Research Gap Analysis

The following research gaps were identified:

1. **Limited Exploration of Auto-Rickshaw-Specific Wind Turbine Designs:** Most existing research focuses on larger-scale wind turbines for general applications. A research gap exists in the lack of dedicated studies addressing the unique design considerations and optimization parameters for small wind turbines specifically tailored for auto-rickshaws.
2. **Insufficient Understanding of Diffuser-Augmented Wind Turbines in Automotive Contexts**: While diffuser-augmented wind turbines (DAWT) show promise in enhancing power output, there is a research gap in understanding their performance within the confined and dynamic environment of auto-rickshaws. Exploring the interaction between the diffuser-augmented turbine and the vehicle's aerodynamics is essential.
3. **Limited Empirical Studies on Auto-Rickshaw Wind Turbine Integration:** While simulation-based studies are valuable, there is a research gap in the scarcity of empirical studies that validate the performance of wind turbines when integrated into actual auto-rickshaw systems. Empirical data is crucial for assessing the practicality, efficiency, and challenges associated with implementation.

Addressing these research gaps would contribute significantly to the advancement of knowledge in the field, ensuring that the design and optimization of small wind turbines for auto-rickshaws are not only theoretically sound but also practically applicable and economically viable in diverse urban setting

2.4 Summary

The literature review sheds light on the complex field of diffuser augmented wind turbines (DAWT), exposing a wide range of research initiatives designed to improve the effectiveness and practicality of wind energy systems. The overview begins with an examination of basic ideas and historical advancements before moving on to landmark research on DAWT aerodynamics, diffuser design, and structural factors. The summary of important results emphasizes how important computational simulations and empirical testing are to improving our knowledge of DAWT performance in many scenarios. The optimization of diffuser geometries, blade designs, and the overall objective of enhancing energy collection in low wind speed settings are noteworthy themes. In addition to presenting the state-of-the-art, the study also points out research gaps and calls for more investigation into topics including techno-economic evaluations and urban wind energy applications.

CHAPTER 3

METHODOLOGY

The project "Integration of Diffuser Augmented Wind Turbine on Automobiles for Power Generation" has a methodology that takes a thorough approach. To start, a thorough evaluation of the literature is conducted to identify existing research gaps and fundamental principles. The careful design and computer-aided modeling of diffuser shells and turbine blades, optimized for maximum aerodynamic performance, come next. In order to evaluate aerodynamic qualities and improve designs, more CFD simulations are run, with an emphasis on pressure distribution and wind flow patterns. In order to validate simulation results, empirical testing entails developing and deploying prototypes on auto rickshaws while gathering data on voltage output and wind speed. The method culminates in repeated validation and optimisation of the designs to ensure improved performance and practical applicability in real-world scenarios.

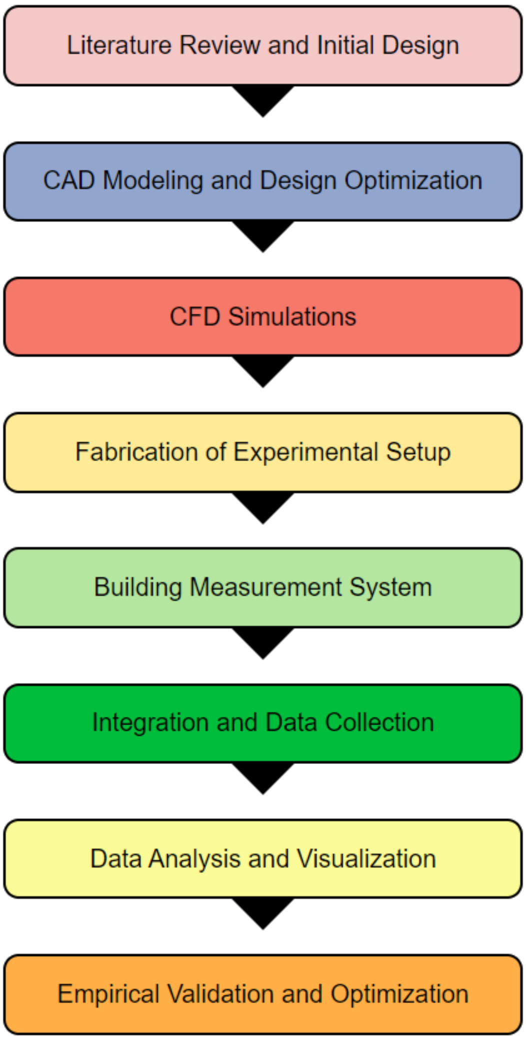


Fig 3.1: Flow Diagram (Methodology)

3.1 DAWT CAD Design Development

This project's Computer-Aided Design (CAD) phase is essential to turning abstract ideas and rough sketches into accurate, realistic models that can be tested, refined, and built. With the use of CAD software, elaborate designs can be produced with great accuracy and visualisable complex geometries can be adjusted before practical production takes place. This section will examine the design process of the Diffuser Augmented Wind Turbine (DAWT) and how it integrates with an auto rickshaw. It will emphasize the measures that were taken to guarantee structural integrity, aerodynamic efficiency, and practical feasibility.

The first design started with the creation of the diffuser shell and turbine blades using sophisticated CAD software. These elements are essential to the DAWT system's operation since the efficiency of energy capture and conversion is directly impacted by their sizes and shapes. In order to increase lift and minimize drag under varied wind conditions, the airfoil shape, chord length, and twist angle were optimized in the blade design. Simultaneously, the diffuser shell was designed to optimize airflow through the turbine, generating a low-pressure area that quickens wind speed and enhances the overall efficiency of the turbine.

Additional design issues arose from the auto rickshaw's integration of the DAWT. In order to guarantee that the turbine's location would not negatively impact the vehicle's stability or fuel efficiency, the CAD models had to take into consideration the aerodynamic interactions between the vehicle and the turbine. For this, a thorough modeling of the auto rickshaw's body and the surrounding aerodynamic flow was needed, taking into account how the moving vehicle would affect the wind turbine's efficiency.

Iterative testing and improvement were crucial to the CAD design process. Computational Fluid Dynamics (CFD) simulations were used on preliminary models to forecast aerodynamic performance and pinpoint possible areas for improvement. Subsequent adjustments to the designs were directed by feedback from these simulations, resulting in increasingly resilient and efficient models. Through the use of CAD software, the design process made it possible to thoroughly explore a range of configurations and materials, which in the end produced a DAWT system that was well-optimized and prepared for manufacture and experimental validation.

3.1.1 Blade Design:

Model 1:

The design and optimization of a compact wind turbine blade for low wind operation is the primary objective of Manoj Kumar Chaudhary's research. The energy absorption mechanism relies heavily on the blade, and effective energy absorption depends on the blade's design. A design point tip speed ratio of around 7 and a solidity range from 4% to 6% yield the maximum Cp for a blade number of 3.

Drawing on the insightful knowledge from Manoj Kumar Chaudhary, a rotor blade was designed that effectively balances a number of variables to improve wind turbine performance. The Clark Y airfoil type, which is well-known for having advantageous lift and drag characteristics, is incorporated into the design in order to facilitate effective energy extraction. For the rotor blade design, the Clark Y airfoil was selected because of its well-established properties that meet the demands of tiny wind turbine applications. For optimum aerodynamic efficiency, the Clark Y profile is a good option because of its well-balanced lift and drag characteristics. It's mild stall characteristics and comparatively high maximum lift coefficient let it maintain lift in a variety of wind conditions, which is important for small-scale wind turbines operating in dynamic settings.

Table 3.1: Blade Dimensions (Model 1)

Dimension	**Model 1**
Blade Length (L)	75 mm
Blade Chord Length (Root)	12 mm
Blade Chord Length (Tip)	8 mm
Blade Thickness (Max)	3 mm
Blade Twist Angle (Root)	15 degrees
Blade Twist Angle (Tip)	5 degrees
Airfoil Profile	NACA 4415
Number of Blades	3
Rotor Diameter	200 mm
Hub Diameter	50 mm

The Clark Y airfoil also has simplicity in design and production, which is essential for real-world use. For integration into a wind turbine system, the blade's length of 100 mm achieves a compromise between compactness and aerodynamic efficiency.

A balanced distribution of lift and drag forces is ensured by the chord length which varies from 16 mm to 12 mm along the blade span to meet the complex aerodynamic needs of various portions. Pitch and twisted angles of 15 degrees were deliberately selected to optimize rotor performance in a range of wind speeds. The twisted angle helps to distribute aerodynamic stresses more evenly. Applied strategically along the airfoil, an 18% thickness provides strength to the blade structure while preserving the fine balance between structural soundness and aerodynamic performance.

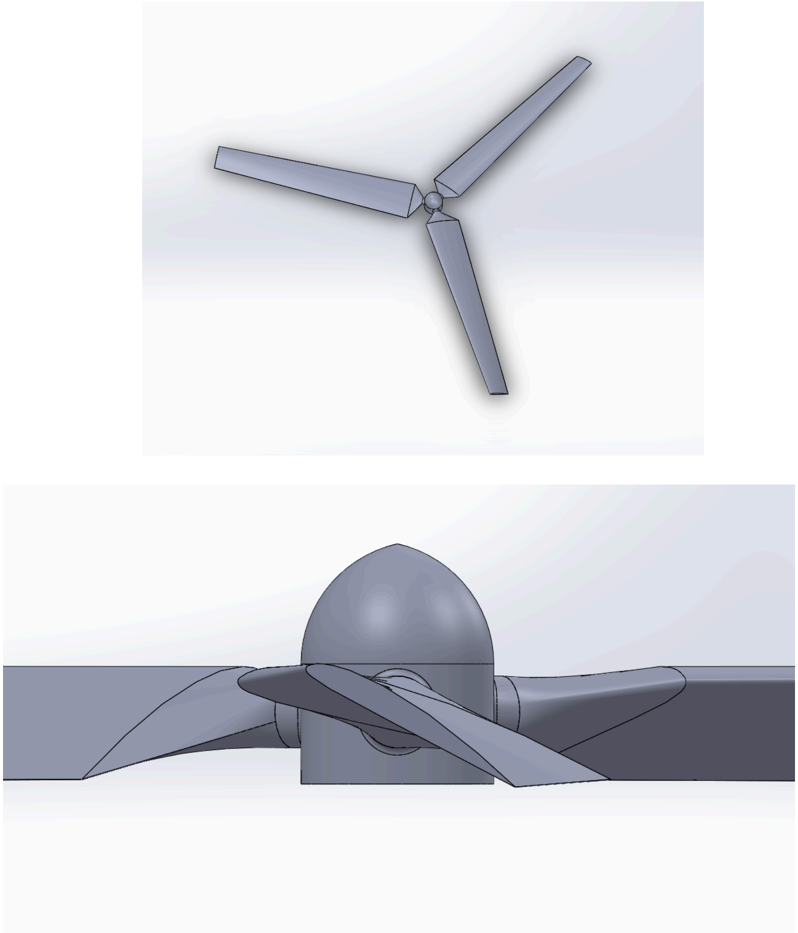


Fig 3.1: Blade CAD Model (Model 1)

Model 2:

A new model with improved specifications has been created to address the limitations of the prior blade design, with the goal of enhancing overall performance and structural integrity. The NACA 4415 airfoil, which is renowned for its balanced aerodynamic qualities and structural resilience, is used in the new blade design. For the new blade model, the chord length is 40mm. This dimension guarantees the best possible balance between structural strength and aerodynamic performance. A longer chord length lowers the possibility of stress concentrations and possible structural failures seen in the previous design by increasing the blade's surface area and improving its capacity to gather wind energy and distribute aerodynamic forces more effectively.

Table 3.2: Blade Dimensions (Model 2)

Dimension	**Model 2**
Blade Length (L)	90 mm
Blade Chord Length (Root)	14 mm
Blade Chord Length (Tip)	10 mm
Blade Thickness (Max)	4 mm
Blade Twist Angle (Root)	12 degrees
Blade Twist Angle (Tip)	3 degrees
Airfoil Profile	NACA 4418
Number of Blades	3
Rotor Diameter	200 mm
Hub Diameter	50 mm

The blade has a specified twist angle of 20 degrees. In order to guarantee a more even distribution of aerodynamic forces along the blade's length, this twist was purposefully added. The twist enhances overall aerodynamic efficiency and lowers the risk of structural stress and deformation by altering the angle of attack along the blade's span.

This helps to maintain effective energy capture across the blade's various portions. The blade's lift-to-drag ratio has been optimized by setting the attack angle at 15 degrees. By optimizing lift and reducing drag, this angle of attack guarantees that the blade runs effectively within the intended range of wind speeds.

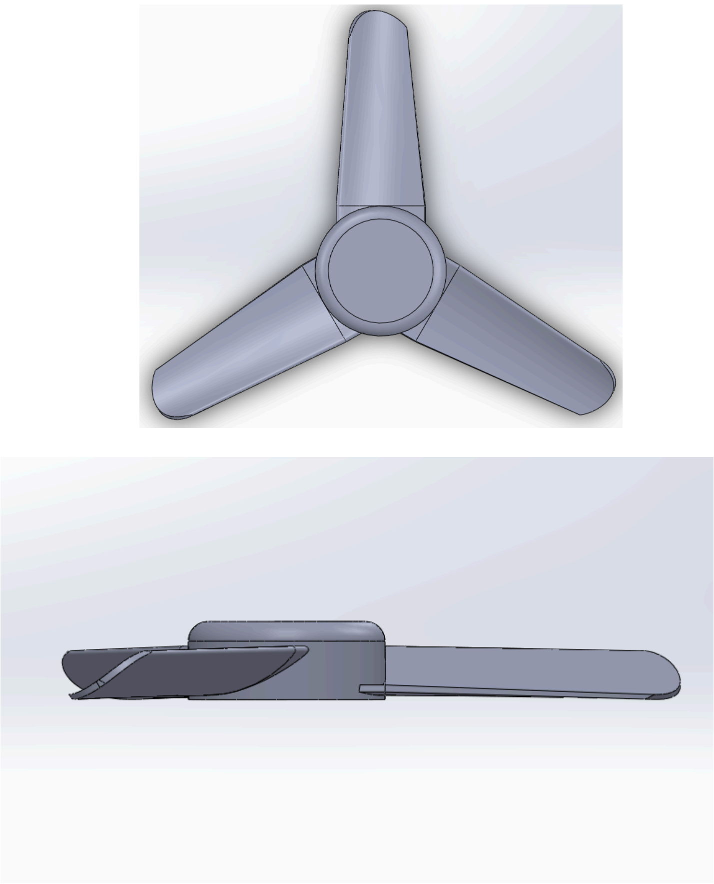


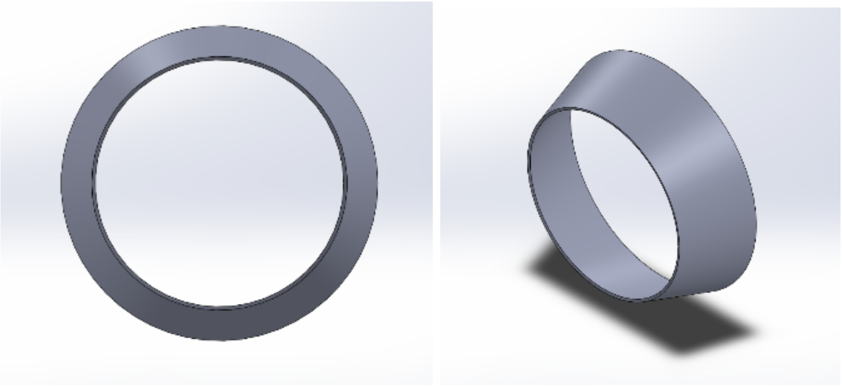
Fig 3.3: Blade Cad Model

The new design balances compactness and aerodynamic efficiency with a blade length of 80mm. While keeping the length reasonable for practical production and integration into the wind turbine system, it guarantees enough surface area for energy collecting. This length also helps maintain the structural integrity of the blade by giving it enough support to endure operational pressures. Comprehensive computational models were used during the design phase to assess structural integrity and aerodynamic performance. With its larger profile, the NACA 4415 airfoil solves the fragility problems seen in the earlier generation, offering improved durability and stiffness. Efficient aerodynamic performance is ensured by the appropriate chord length, twist angle, and attack angle, which also equally distribute loads over the blade's structure.

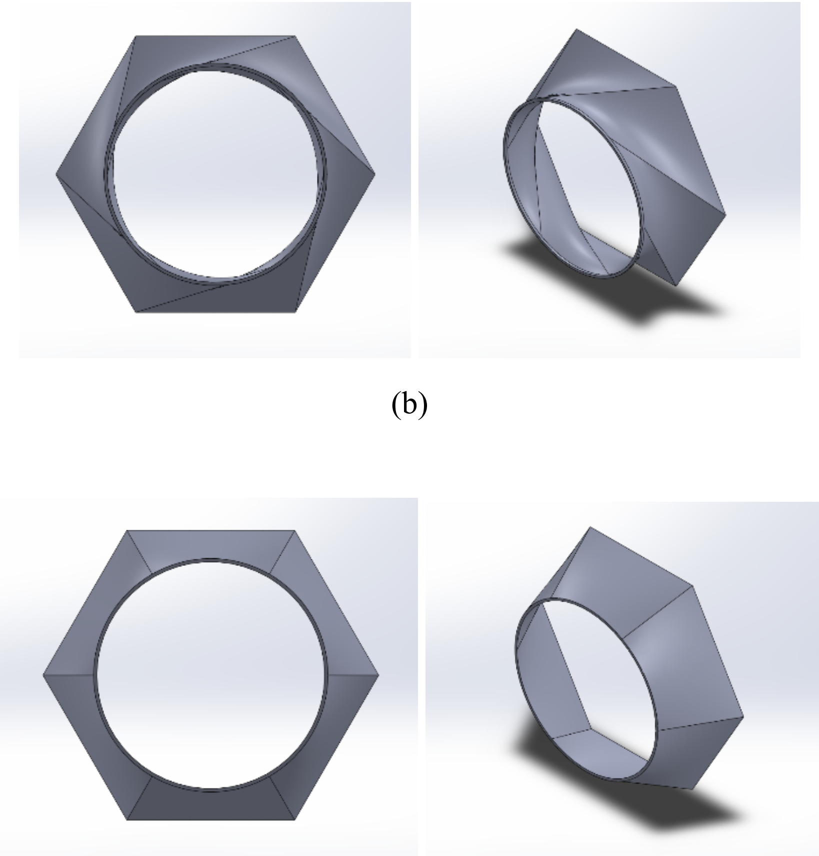
3.1.2 Diffuser Shell Design:

To maximize a wind turbine's performance and power generating capabilities, a basic diffuser shell design must carefully take into account a number of parameters. In keeping with S.A.H. Jafari observations, special consideration is devoted to important variables such the diffuser's length, the discrepancy between the intake and outlet radii, and the shell's overall measurements.

To guarantee compatibility with a small design appropriate for installation on an Auto-Rickshaw, a three wheeled, battery-powered vehicle, the rotor diameter (D) is fixed at 202mm.The diffuser length is 80mm, in accordance with S.A.H. Jafari research, which is important for reducing flow separation and improving pressure recovery. In order to achieve optimal power generation while keeping a compact design, the distance between the inlet and outlet radii (H) is set at 25mm. These dimensions, which represent the best-practice recommendations for optimizing the power coefficient (Cp), fit within the designated ratio ranges, with the H/D ratio ranging between 0.1 and 1.15 and the L/D ratio at 0.4. This careful consideration of dimensions guarantees that the frustum diffuser shell is optimized for effective power extraction while meeting the limitations of the Auto-Rickshaw platform, providing an application that strikes a compromise between practicality and performance.



(a)



(b)

(c)

Fig 3.4: Diffuser Shell CAD Model (a)Circular Diffuser Shell, (b) Circular to Twisted Hexagonal Diffuser Shell, (c) Circular to Hexagonal Circular Shell.

Apart from following these basic design guidelines, SolidWorks was utilized to conceptualize and develop three separate diffuser shell models. Every model had a distinct outlet design to investigate the effects of various geometries on the efficiency of power generation. The initial concept highlighted ease of production and simplicity with its circular outlet. In order to investigate if a more intricate geometric form may affect the diffuser's flow dynamics, the second model had a hexagonal outlet. The third model explored the possible advantages of a little twist in the geometry by adding an element of aerodynamic variation and including a sixty-degree twisted hexagonal outlet.

Table 3.3: Diffuser Shell Dimensions

Dimension	**Diffuser Shell**
Length	80 mm
Height	300 mm
Width	300 mm
Inlet Diameter (D_in)	202 mm
Outlet Diameter (D_out)	252 mm
Diffuser Angle	10 degrees
Wall Thickness	3 mm
Material	Plane Sheet Steel
Number of Sections	4
Support Structure Diameter	20 mm
Flange Diameter	60 mm
Flange Bolt Hole Diameter	8 mm
Surface Finish	Painted
Reinforcement Bars	2 (Iron Bars)

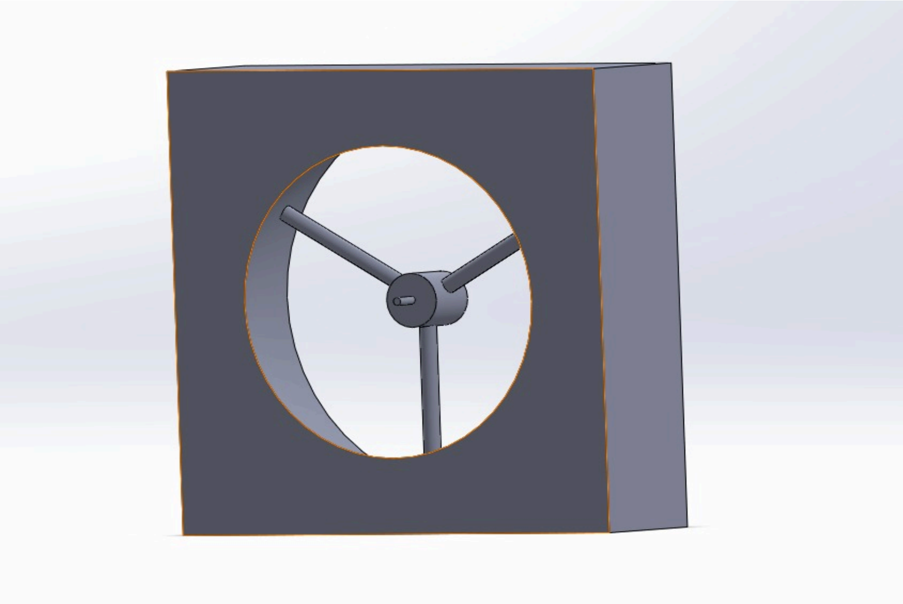


Figure 3.5: Selected Shell Design

3.1.3 Auto Rickshaw Structure Design:

A CAD model of the autorickshaw has been created in order to maximize the wind velocity at the turbine and optimize the location of the wind turbine on the vehicle. The best location for the installation of turbines will be determined by simulations using this model. The proportions of the autorickshaw model are as follows: it is meant to be exactly 2891 mm long, 1761 mm high, and 1088 mm wide. These proportions faithfully capture the general dimensions of an autorickshaw, giving the simulations a solid foundation.

Table 3.4: Auto Rickshaw Dimensions

Dimension	**Value**
Overall Length	2891 mm
Overall Width	1088 mm
Overall Height	1761 mm
Ground Clearance	200 mm
Cabin Length	1600 mm
Cabin Width	1200 mm
Cabin Height	1500 mm
Roof Height	1761 mm
Door Width	700 mm
Door Height	1200 mm
Seat Height	450 mm
Seat Depth	400 mm

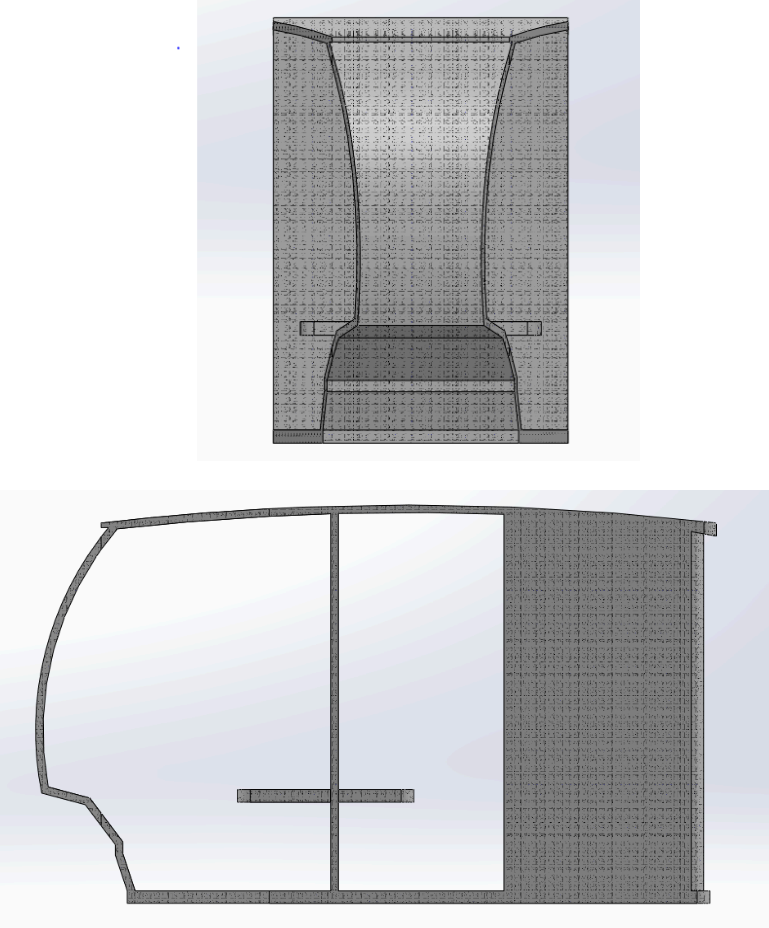


Fig 3.6: Auto Rickshaw Structure Cad Model

In the design phase, Solidworks software was used to create a -dimensional model of the autorickshaw. The autorickshaw's essential geometric elements are all included in the model, guaranteeing that the simulations will faithfully capture the aerodynamic behavior of the real vehicle. Finding the places on the autorickshaw where the wind velocity is highest is the goal because this is where the wind turbine will be most effectively placed to capture wind energy.

3.2 Fabrication of The Diffuser Shell

3.2.1 Fabrication Processes

In order to guarantee structural integrity and the best possible aerodynamic performance, a range of materials and machining processes were used during the manufacture of the diffuser shell for the Diffuser Augmented Wind Turbine (DAWT) on the auto rickshaw.

Iron angles, paint, pipe iron bars, plane sheet steel, and a variety of nuts and bolts were utilized in the building. The steps involved in creating the diffuser shell, together with the precise measurements needed, are described in detail in the paragraphs that follow.

Material Preparation

Getting the requisite materials was the first step in the fabrication process. Iron angles were utilized to offer structural support, and plane sheet steel was chosen for its strength and longevity. The piping was made of iron bars, and the parts were secured together with nuts and bolts. To guarantee that the finished assembly would survive operational stresses and climatic conditions, each material was carefully chosen.

Table 3.5: Material Used in Fabrication

Material	Quantity	Dimensions
Plane Sheet Steel	3 sheets	300 mm x 300 mm x 5 mm (length x width x thickness)
Iron Angles	4 pieces	300 mm x 40 mm x 40 mm x 5 mm (length x width x height x thickness)
Iron Bars	2 bars	600 mm x 20 mm (length x diameter)
Nuts and Bolts	20 sets	M10 x 30 mm (diameter x length)
Paint	2 liters	High-durability, anti-corrosion paint

Cutting and Shaping

The next stage was to cut and shape the plane sheet steel and iron angles to the necessary dimensions when all the materials were in place. The body of the diffuser shell was formed by cutting the plane sheet steel into panels that were 300 mm long, 300 mm wide, and 80 mm high using precision cutting equipment. To act as the diffuser's frame, iron angles were cut to the same length (300 mm), which helped to support and preserve the diffuser's shape. Additionally, the iron bars were cut to the proper lengths for the pipe parts, making sure that they matched the diffuser shell's overall measurements.

Assembly and Welding

After all the parts were trimmed to size, the diffuser shell's basic frame was formed by welding the iron angles together. The precision and strength of the frame's welding ensured a firm base for the panels made of planar sheet steel. After that, nuts and bolts were used to fasten the panels to the frame, resulting in a sturdy and solid construction. To add more support, iron bars that were cut to the proper lengths for structural reinforcement were welded to the frame at key points.

Painting and Finishing

After the primary assembly was completed, the diffuser shell underwent a painting process to enhance its durability and aesthetic appeal. The entire structure, measuring 300 mm in length, 300 mm in width, and 80 mm in height, was coated with a protective layer of paint to prevent corrosion and weathering, ensuring long-term performance in various environmental conditions. The paint also provided a professional finish to the diffuser shell, making it visually appealing.

Final Assembly and Quality Check

In the fabrication process, a comprehensive inspection and quality check were the last steps. Every part was inspected to guarantee correct positioning and sturdy attachment. Weld integrity was checked and nuts and bolts were tightened. After completion, the diffuser shell underwent a battery of tests to confirm its aerodynamic effectiveness and structural stability.

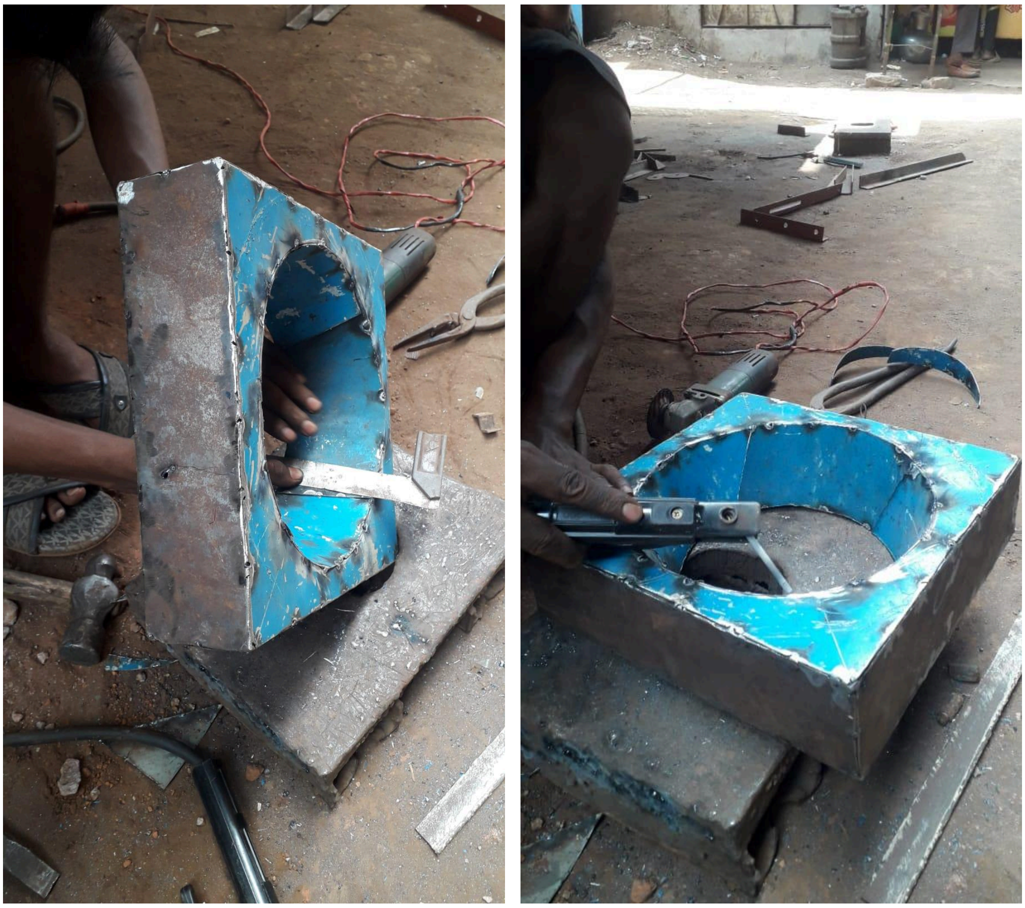


Fig 3.7: Shell making process

The diffuser shell's effective manufacturing was a significant turning point in the DAWT's experimental setup on the auto rickshaw. The diffuser shell was made strong and efficient, prepared for testing and deployment in real-world scenarios, by using premium materials and precise machining techniques in addition to adhering to the given dimensions. This thorough manufacturing procedure set the stage for the DAWT system's later experimental assessment and optimization.

3.2.2 Machine Tools

A variety of machinery were used in the manufacture of the diffuser shell for the Diffuser Augmented Wind Turbine (DAWT) in order to guarantee accuracy, effectiveness, and structural integrity. From cutting and shaping materials to assembling and polishing the finished product, every equipment was essential to the fabrication process at various points. The machinery utilized and their characteristics are listed in detail in the accompanying table, which also emphasizes their significance and role in the diffuser shell's effective construction.

Table 3.6: Machine Tools Specifications

Process	**Machine Used**	**Specifications**
Cutting and Shaping	CNC Plasma Cutter	Cutting area: 3000 x 1500 mm
		Cutting thickness: up to 25 mm for steel
		Cutting speed: up to 10,000 mm/min
		Accuracy: ±0.1 mm
Welding	MIG Welding Machine	Welding current: 50-300 A
		Voltage: 220-240 V
		Duty cycle: 60% at 250 A
		Wire feed speed: 1.5-15 m/min
Drilling	Drill Press Machine	Drilling capacity: 32 mm in steel
		Spindle speed: 100-3000 RPM
		Motor power: 1.5 kW
Painting	Spray Painting Booth	Booth dimensions: 4.5 x 3 x 2.5 m
		Airflow: 0.3-0.5 m/s
		Filtration: High-efficiency particulate air (HEPA)
Grinding and Finishing	Angle Grinder	Disc diameter: 125 mm
		No-load speed: 11,000 RPM
		Power input: 750 W

A thorough overview of the equipment used to fabricate the diffuser shell is given in this table and its accompanying descriptions, which also highlight the equipment's specifications and the roles they performed in guaranteeing the development of a reliable and efficient DAWT system.

3.3 Building Measurement System

A sturdy measurement system was constructed for the Diffuser Augmented Wind Turbine (DAWT) experimental setup in order to obtain vital information on wind speed and the voltage produced by the turbine. Two separate circuits, each managed by a separate ESP8266 microcontroller, make up this system. By utilizing specially made sensors and a dependable power source, the circuits were made to measure generated voltage and wind speed. The steps and parts used to build this measurement system are explained below.

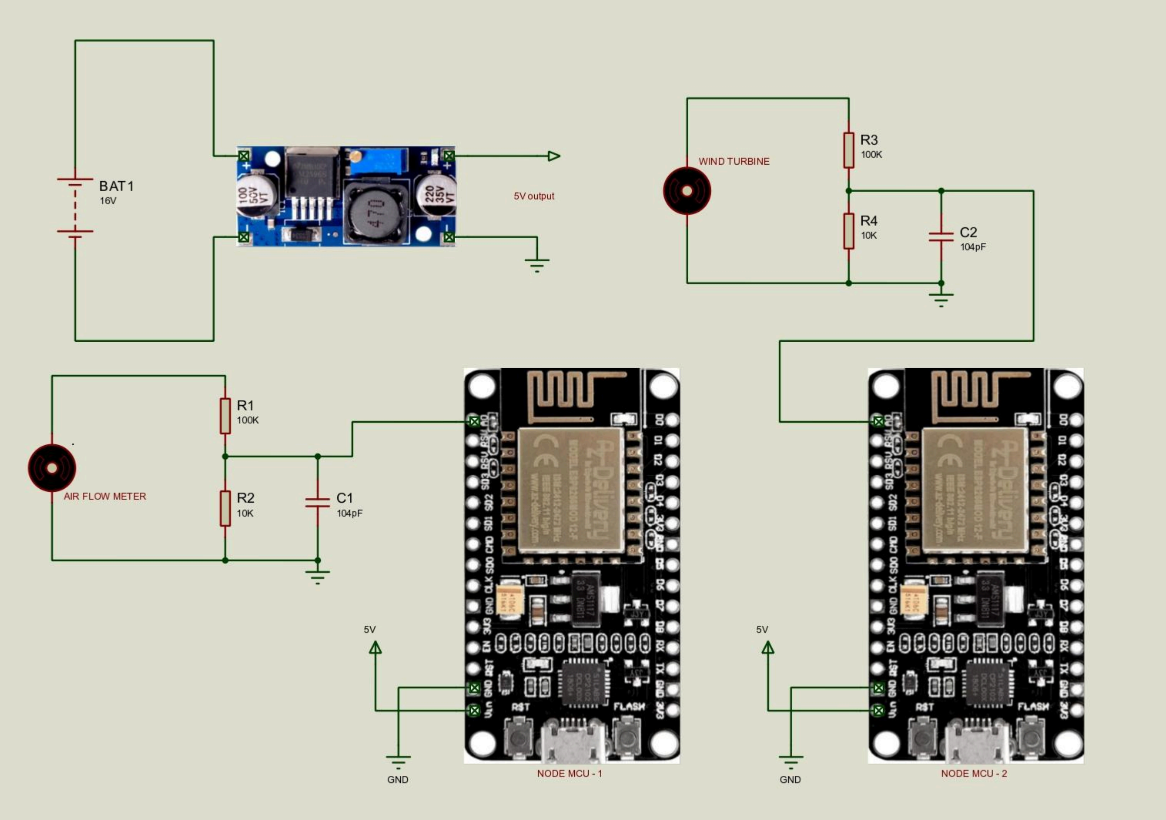


Fig 3.8 : Circuit diagram of the IOT system

3.3.1 Wind Speed Measurement

A free-spinning DC motor was used in the first circuit system, which was intended to measure wind speed using a homemade anemometer. The wind-driven rotation of the motor produced a voltage that was proportionate to the wind speed. The first ESP8266 microcontroller, designated as Node MCU-1 in the circuit diagram, read this voltage.

Components and Connections:

- A voltage divider circuit with resistors R1 (100K ohms) and R2 (10K ohms) and a capacitor C1 (104 pF) was linked to an air flow meter (DC motor). This configuration made the voltage signal stable.
- The voltage divider's output was connected to Node MCU-1's analog input, where it was analyzed and transformed into information about wind speed.

3.3.2 Voltage Measurement from Wind Turbine

The wind turbine, which also employed a free-spinning DC motor, produced voltage, which was measured by the second circuit system. The second ESP8266 microcontroller, designated as Node MCU-2 in the circuit diagram, read the generated voltage.

Components and Connections:

- In order to stabilize the voltage signal, the wind turbine's DC motor output was linked to another voltage divider circuit that included a capacitor C2 (104 pF), resistors R3 (100K ohms) and R4 (10K ohms).
- Node MCU-2 received this stabilized voltage as an analog input, analyzed it, and output real-time voltage data.

3.3.3 Power Supply

A common power supply consisting of four lithium-ion batteries and a voltage regulator module powered both microcontroller circuits. The voltage regulator module reduced the 16V total voltage supplied by the batteries to 5V so that the ESP8266 microcontrollers could be powered securely.

Components and Connections:

- To generate a total voltage of 16 volts, a series connection of four 4 volt lithium-ion batteries was used as the power source.
- The 16V was step-down to a steady 5V output using a voltage regulator module, guaranteeing that Nodes MCU-1 and MCU-2 would always have power.
- Both microcontrollers' power input pins were linked to the regulated 5V output, guaranteeing that they would get the voltage required for operation.

3.3.4 Circuit Design Overview

The circuit design, as shown in the attached diagram, makes sure that every system uses the same power supply but functions independently of one another. Accurate measurement and dependable sensor performance are ensured by the meticulous assembly of parts and connections.

- **Nodes MCU-1 and MCU-2:** These microcontrollers are in charge of gathering and analyzing data from the anemometer and the DC motor of the wind turbine, respectively.
- **Voltage Divider Circuits:** These circuits stabilize the voltage signals before feeding them into the microcontrollers. They are made of resistors and capacitors.
- **Power Supply:** The voltage regulator module and lithium-ion batteries work together to offer a steady and dependable power source for the whole measurement system.

The accurate collection of wind speed and voltage generation data, as well as the provision of critical insights for assessing the DAWT's performance on the auto rickshaw, were made possible by this extensive measurement system. The system's resilience and dependability under real-world situations were guaranteed by the integration of specially designed sensors, microcontrollers, and a reliable power supply.

3.4 Calibration of Wind Velocity Measurement Device

Iterative testing and improvement were crucial to the CAD design process. Computational Fluid Dynamics (CFD) simulations were used on preliminary models to forecast aerodynamic performance and pinpoint possible areas for improvement. Subsequent adjustments to the designs were directed by feedback from these simulations, resulting in increasingly resilient and efficient models. Through the use of CAD software, the design process made it possible to thoroughly explore a range of configurations and materials, which in the end produced a DAWT system that was well-optimized and prepared for manufacture and experimental validation.

The wind speed inside the wind tunnel was measured using a widely used, AIRFLOW LCA 6000 anemometer as the first step in the calibration process. In order to make sure that the wind speed remained constant and to detect any differences in airflow, the anemometer was positioned at several positions along the tunnel. To confirm that our wind tunnel offered a trustworthy baseline for calibration, this step was essential.

Fig 3.9: Anemometer

AIRFLOW LCA 6000 Specifications are:

Table 3.7: AIRFLOW LCA 6000 Specifications

Specification	**Description**
Measurement Range	0.3 to 30 m/s
Accuracy	±1.5% of reading
Resolution	0.01 m/s
Temperature Range	-10°C to +50°C
Humidity Range	0 to 100% RH
Display Type	Digital LCD
Power Supply	9V Battery
Dimensions	170 mm x 85 mm x 40 mm
Weight	300 g
Data Logging Capability	Yes
Interface	USB
Sensor Type	Hot Wire Anemometer
Operating Modes	Continuous and Average Modes
Calibration	Factory Calibrated
Response Time	<1 second
Accessories Included	Carrying Case, USB Cable, Manual

After confirming the tunnel's wind speed, The homemade anemometer was placed in the same spot as the store-bought one that had consistently given reliable readings. A little DC motor that rotated to produce a voltage according to wind speed was the basis for our homemade anemometer. The voltage output was measured corresponding to various wind speeds by connecting the DC motor to a voltmeter.

The commercial anemometer was used to measure the voltage produced at several known wind speeds and recorded it using the DIY anemometer. A calibration curve was then created using this data, connecting the voltage output of the custom anemometer to the actual wind velocity. By graphing the measured voltages against the relevant wind speeds and fitting a linear regression model to the data, the calibration curve was obtained.

The resulting calibration equation took the form:

$$V_{wind} = a \times V_{measured} + b \tag{1.7}$$

where:

- V_{wind} is the wind velocity,
- $V_{measured}$ is the voltage output from the custom anemometer,
- a and b are the calibration constants determined from the regression analysis.

It was possible to accurately determine the wind velocity using this equation by converting the voltage data from the custom anemometer. Additional experiments were carried out to confirm the calibration's correctness. The wind speeds were measured using both bespoke and commercial anemometers at different fan speeds, and the findings were compared . The measurements' strong agreement supported the accuracy of our calibration process.

3.5 Integration of IoT in Data Collection

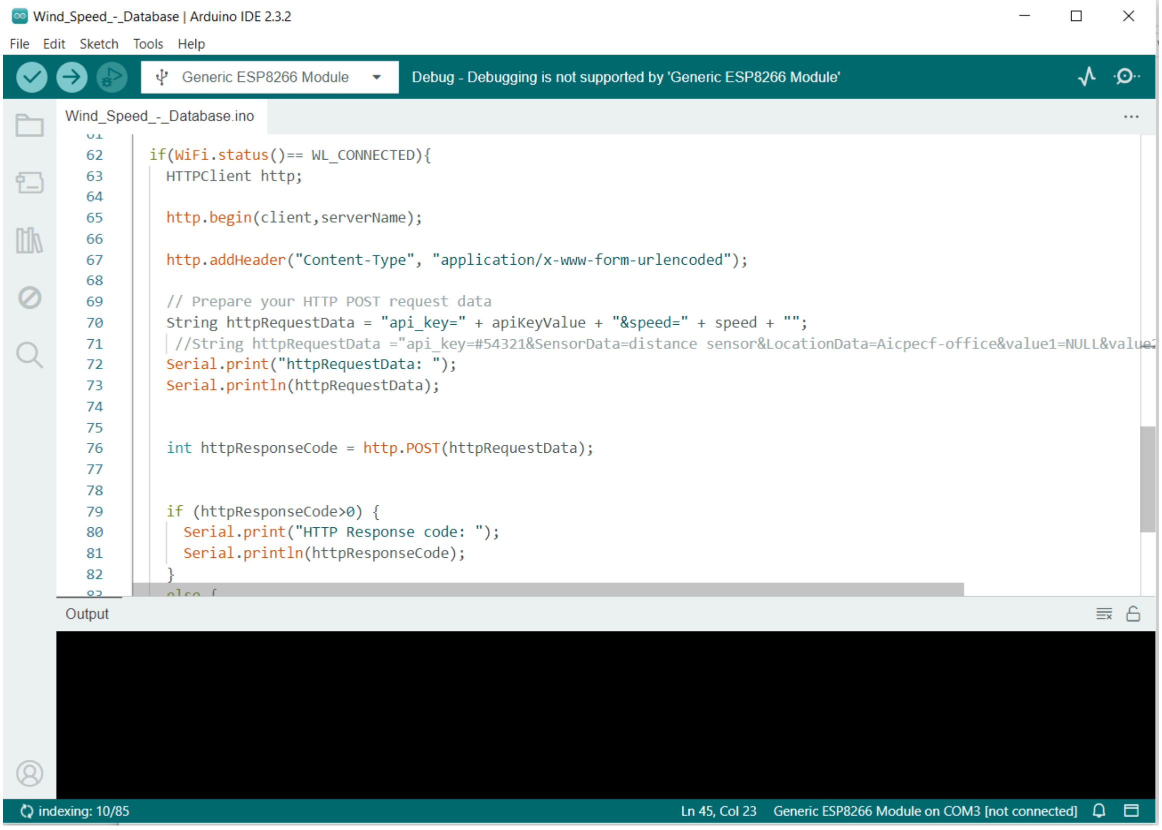
Real-time monitoring and recording of wind speed and voltage generation was made possible by the Internet of Things' (IoT) incorporation into the data collecting process for the DAWT (Diffuser Augmented Wind Turbine) experimental setup on the auto rickshaw. Two ESP8266 microcontrollers, each in charge of a distinct measurement task, were used to accomplish this. Using the Arduino IDE, separate scripts were written to instruct the microcontrollers to capture voltage and wind speed data and send it to a cloud-based database for additional analysis. The procedure for incorporating IoT into the data collection system is explained below.

Table 3.8: Components of IoT System

Component	**Specification**
Battery (BAT1)	Lithium-Ion Battery Pack, 16V
Voltage Regulator Module	Input Voltage: 7V to 35V Output Voltage: 5V Current: Up to 3A
Anemometer (Air Flow Meter)	Model: AIRFLOW LCA 6000, Measurement Range: 0.3 to 30 m/s, Accuracy: ±1.5% of reading, Resolution: 0.01 m/s, Sensor Type: Hot Wire Anemometer
Free DC Motor	Voltage: 24V
Resistors	100K Ohm, 10K Ohm
Capacitor	104 pF (picofarads)
Microcontroller	Model: ESP8266 Operating Voltage: 3.3V Wi-Fi Module: 802.11 b/g/n GPIO Pins: 17 (including 1 ADC pin) Flash Memory: 4MB Processor: Tensilica L106 32-bit RISC Clock Speed: 80 MHz

3.4.1 IoT Integration for Wind Speed Measurement

Using a handmade anemometer, the first ESP8266 microcontroller (Node MCU-1) was configured to measure wind speed. With the use of a DC motor that spun freely, the anemometer produced a voltage that was proportionate to the wind speed. The steps in the procedure are as follows:



```
if(WiFi.status()== WL_CONNECTED){
  HTTPClient http;

  http.begin(client,serverName);

  http.addHeader("Content-Type", "application/x-www-form-urlencoded");

  // Prepare your HTTP POST request data
  String httpRequestData = "api_key=" + apiKeyValue + "&speed=" + speed + "";
  //String httpRequestData ="api_key=#54321&SensorData=distance sensor&LocationData=Aicpecf-office&value1=NULL&value
  Serial.print("httpRequestData: ");
  Serial.println(httpRequestData);


  int httpResponseCode = http.POST(httpRequestData);


  if (httpResponseCode>0) {
    Serial.print("HTTP Response code: ");
    Serial.println(httpResponseCode);
  }
```

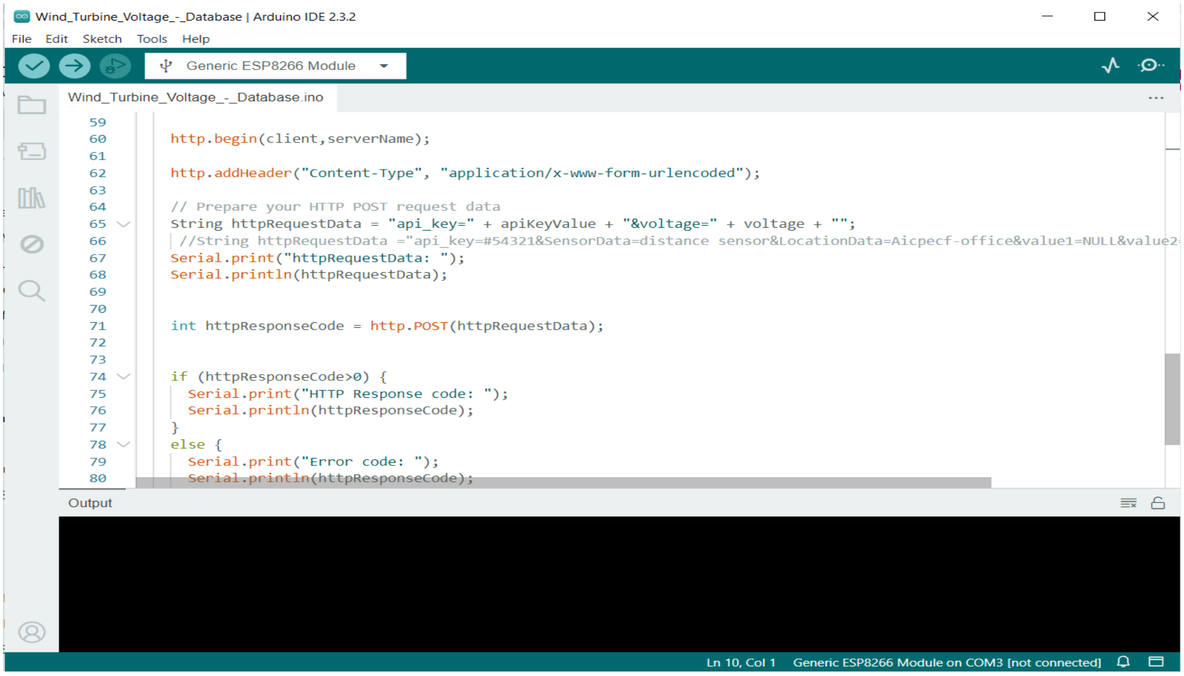
Fig 3.10: Code of the MCU

- **Setup and Initialization:**
  - The microcontroller was set up to communicate with a cloud server by connecting to a Wi-Fi network.
  - The Arduino sketch contained the libraries needed for data handling and Wi-Fi connectivity.
- **Voltage Reading and Conversion:**
  - The voltage produced by the anemometer was read using the ESP8266's analog input pin.
  - The wind speed value was then obtained by applying a pre-established calibration equation to this voltage.
- **Data Transmission:**
  - Using HTTP POST requests, the computed wind speed was submitted to a cloud-based database.
  - To make managing and storing the data in the database easier, it was structured as JSON.

For this procedure, an Arduino sketch named (Wind_Speed_-_Database.ino) has routines for reading voltage, converting it to wind speed, and sending the information over Wi-Fi.

3.4.2 IoT Integration for Wind Turbine Voltage Measurement

The voltage produced by the DC motor of the wind turbine was intended to be measured by the second ESP8266 microcontroller (Node MCU-2). The steps involved in the integration process were the same as those in the wind speed measurement system:



```

http.begin(client,serverName);

http.addHeader("Content-Type", "application/x-www-form-urlencoded");

// Prepare your HTTP POST request data
String httpRequestData = "api_key=" + apiKeyValue + "&voltage=" + voltage + "";
 //String httpRequestData ="api_key=#54321&SensorData=distance sensor&LocationData=Aicpecf-office&value1=NULL&value2
Serial.print("httpRequestData: ");
Serial.println(httpRequestData);


int httpResponseCode = http.POST(httpRequestData);


if (httpResponseCode>0) {
  Serial.print("HTTP Response code: ");
  Serial.println(httpResponseCode);
}
else {
  Serial.print("Error code: ");
  Serial.println(httpResponseCode);
```

Fig 3.11 : Code of the other MCU

- **Setup and Initialization:**
  - The microcontroller was set up to establish a connection with Node MCU-1 on the same wireless network.
  - The Arduino sketch contained libraries that were needed for data handling and Wi-Fi.
- **Voltage Reading:**
  - The voltage produced by the wind turbine was read using the ESP8266's analog input pin.
  - Without any additional conversion, this raw voltage data was sent straight to the cloud-based database.
- **Data Transmission:**
  - HTTP POST requests were used to transfer the voltage data to the cloud database.
  - To guarantee that the data would work with the database structure, it was structured as JSON.
  - The "(Wind_Turbine_Voltage_-_Database.ino)" Arduino sketch had routines for both reading and sending the voltage to the cloud server.

CHAPTER 4

Results and Simulations

The wind turbine blade and diffuser shell ANSYS Fluent simulation provided detailed insights into the aerodynamic performance. Important information on the thrust force, pressure distribution, and air velocity that clarified the blade's efficiency and potential for power generation was supplied by the blade simulation. Simultaneously, the diffuser shell simulation produced vital information on pressure changes and air velocity, crucial for understanding the augmentation effects. Areas of higher and lower pressure were identified by the diffuser shell pressure distribution, which affected the Diffuser Augmented Wind Turbine's (DAWT) overall performance.

4.1 Simulations

4.1.1 CFD Simulation of DAWT Blade Aerodynamics

The Diffuser Augmented Wind Turbine (DAWT) blade's aerodynamic performance and thrust forces were assessed using a specialized Computational Fluid Dynamics (CFD) simulation. The simulation's goal was to comprehend the pressure distribution and aerodynamic forces operating on the turbine blade under particular circumstances using ANSYS Fluent.

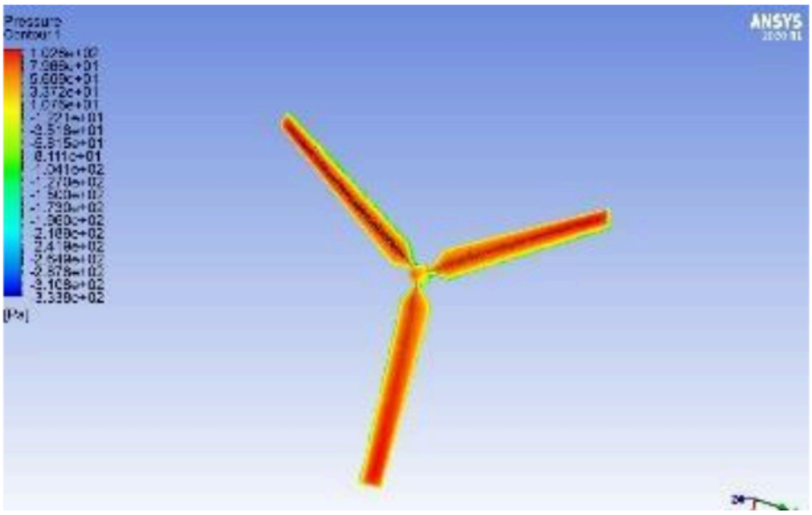
Simulation Setup

The 212 mm in diameter and 20 mm in height cylindrical area encloses the DAWT blade model. The blade surface was subtracted from this cylindrical enclosure using a boolean subtract function, creating a revolving zone. The rotating region was named for this recently formed area. A second enclosure was made as well, and it was given the term static region. Its measurements were 312 mm in width, 312 mm in height, and 600 mm in length. To create a comprehensive computational domain, the revolving region was subtracted from the static region using a boolean subtract operation once more. The model was ready after completing the following steps:

- The static region's inlet and outlet faces were identified and designated appropriately.
- Every one of the blade's 42 faces was chosen and given a name as the blade surface.
- The use of the default mesh settings ensured a balanced approach between accuracy of the solution and computational efficiency.

Key simulation parameters comprised:

- Standard k-epsilon (k-ε) turbulence model with standard wall functions is the viscous model.
- 30 km/h is the inlet wind velocity.
- Gravity: 9.82 m/s^ in the direction of negative y.
- Rotating Region Conditions: A mesh movement with an angular velocity of 740 rpm was applied, and the rotational axis was set along the y-axis.



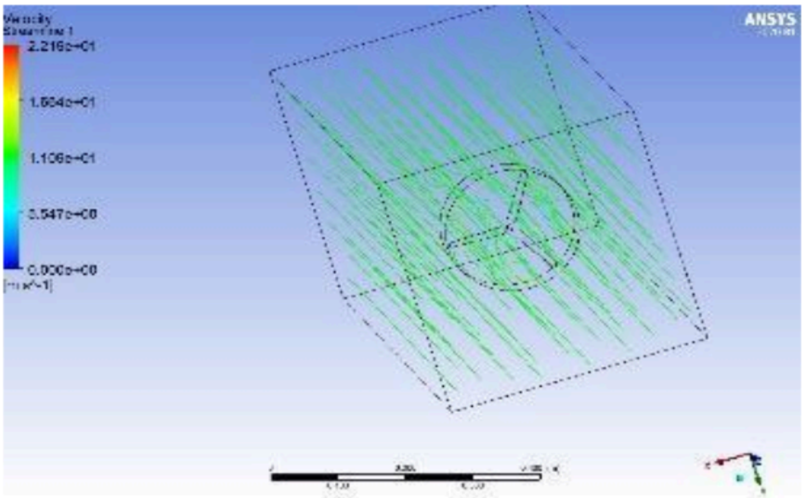


Fig 4.1: Pressure Contour of Blade (Model 1)

Although the current wind turbine blade design is innovative in theory, it has a number of serious flaws that hinder its overall performance and practical implementation. The lack of rigidity is one of the main problems. Despite being aerodynamically effective, the narrow airfoil construction of the blade is unable to provide it the required structural strength. This shortcoming was most noticeable in operating simulations and real-world testing, where the blade flexed and became unstable. Under severe stress circumstances, this kind of behavior may result in ineffective energy capture and possible structural failure. The narrow contour of the blade further adds to its brittleness.

When a physical model was attempted to be printed by 3D printing, it was discovered that the structure shattered quickly, a symptom that the design is not strong enough to endure the demands of everyday operation.

The design's airfoil is noticeably overly thin, which makes it more difficult for the blade to keep its shape when subjected to aerodynamic loads. Although thin airfoils can improve aerodynamic efficiency, they cannot add a substantial amount of weight without sacrificing interior volume for the required reinforcements. Due to the inadequate thickness of the airfoil, the blade is unable to distribute the aerodynamic forces it receives, which can result in significant stress concentrations and possible failure sites. The blade bent and twisted excessively during the simulations, reducing its aerodynamic efficiency and raising the possibility of structural damage. This problem is made worse by insufficient internal reinforcement, which makes it difficult for the blade to control the aerodynamic loads and creates serious structural problems.

Furthermore, the design presents significant manufacturing issues, especially in the context of 3D printing. It is challenging to produce printed models with consistent quality and structural integrity due to the blade's thin and complex construction. The material's fragility throughout the printing process raises the possibility that even little flaws or inconsistent parts could cause a disastrous failure. The requirement for a design that can be consistently produced using the technologies now in use is highlighted by this fragility during the production process.

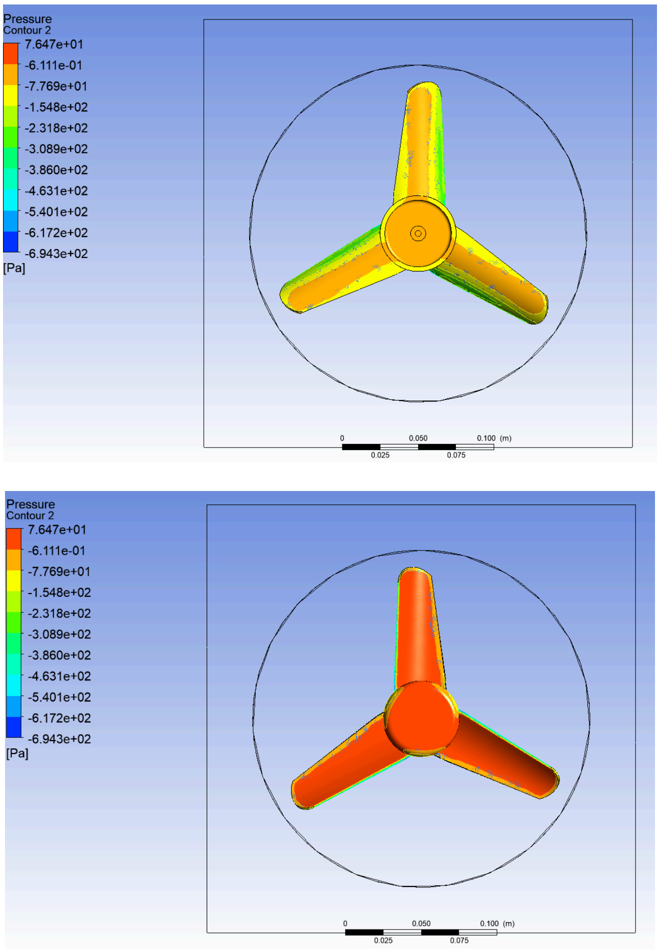


Fig 4.2 : Pressure Contour of Blade (Model 2)

Important new information about the DAWT blade's aerodynamic performance was provided by the simulation. The thrust force exerted on the blade and the pressure distribution across its surface were important findings.

- **Thrust Force:** It was discovered that the DAWT blade was subjected to a thrust force of 1.0501263 N. This number represents the aerodynamic force that rotational motion and wind flow apply to the blade.
- **Pressure Contours:** Pressure contour plots were used to visualize the pressure distribution on the blade surface. These plots showed the blade's high and low pressure areas, giving an accurate depiction of the aerodynamic loading the blade experiences when operating.

The DAWT blade's comprehensive aerodynamic properties, which are critical for enhancing blade performance and design, were disclosed by the CFD research. As would be expected from typical aerodynamic behavior, the pressure contour plots demonstrated a distinct distribution of pressure across the blade, with higher pressures on the leading and lower pressures on the trailing edges.

The thrust force value, which is essential to the DAWT system's overall performance, shows how well the blade converts wind energy into mechanical energy. Aerodynamic loading patterns and rotating speed are important factors that guide future design refinements and optimizations.

The outcomes of the simulation offer a strong basis for improving the DAWT blade design, with an emphasis on optimizing energy harvesting while preserving structural integrity. The turbine's blade shape and material choice will be improved with the use of these insights, resulting in optimal performance under real-world circumstances.

The aerodynamic behavior of the DAWT blade is simulated using CFD, providing useful information on thrust forces and pressure distribution. The results highlight the value of a thorough aerodynamic analysis in maximizing the energy capture efficiency of turbine blade design. The findings will direct subsequent design iterations and empirical validations, assisting in the creation of high-performing DAWT systems for environmentally friendly energy sources. As a result of these computational insights, future research will concentrate on experimental validation and optimization, opening the door for real-world uses in urban wind energy harvesting.

4.1.2 CFD Analysis of Diffuser Shell

A similar setup was used for the simulation of a frustoconical diffuser shell, but no rotational or static domains were introduced. This approach enabled a comprehensive evaluation of the performance of a diffuser that redirects and accelerates wind without using the rotational dynamics present in blade simulations.

Standard air density and atmospheric conditions were maintained and the wind speed at the inlet was fixed. The simulation results include important parameters such as pressure distribution, velocity field, and streamline pattern around the diffuser shell. This simulation strategy examines the aerodynamic properties of the rotor blades and frusto-conical diffuser housing individually to understand their performance holistically and refine and optimize the overall wind turbine design to improve energy production.

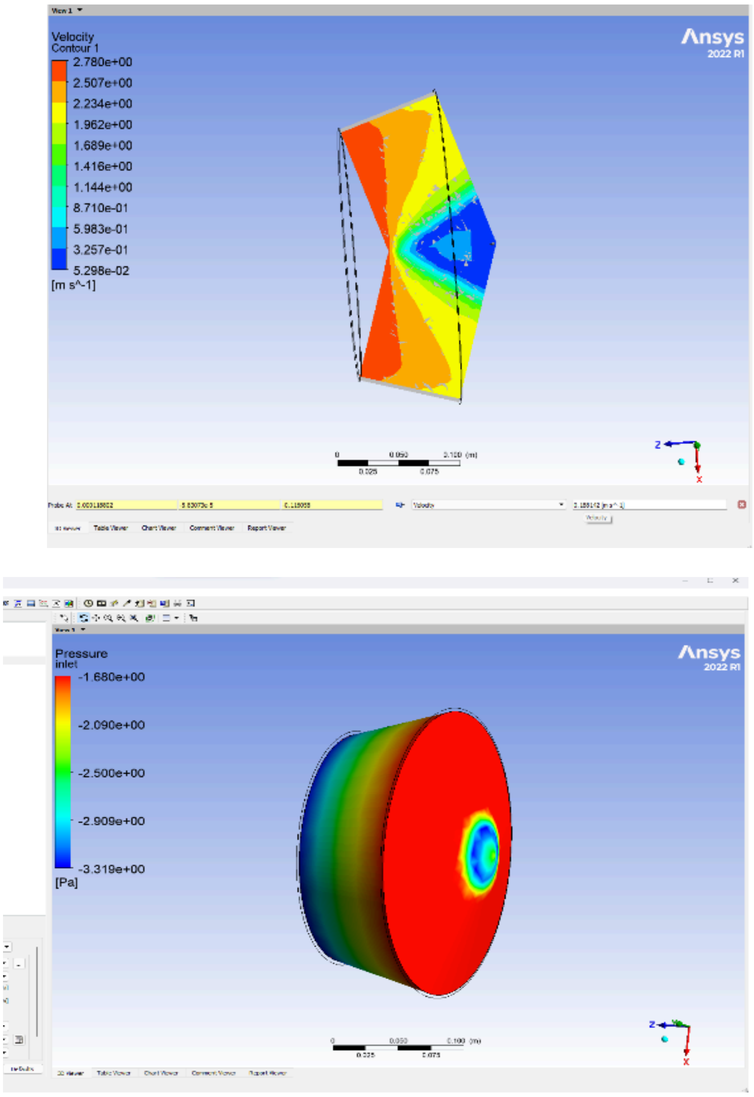


Fig 4.3: CFD Simulation on Diffuser Shell

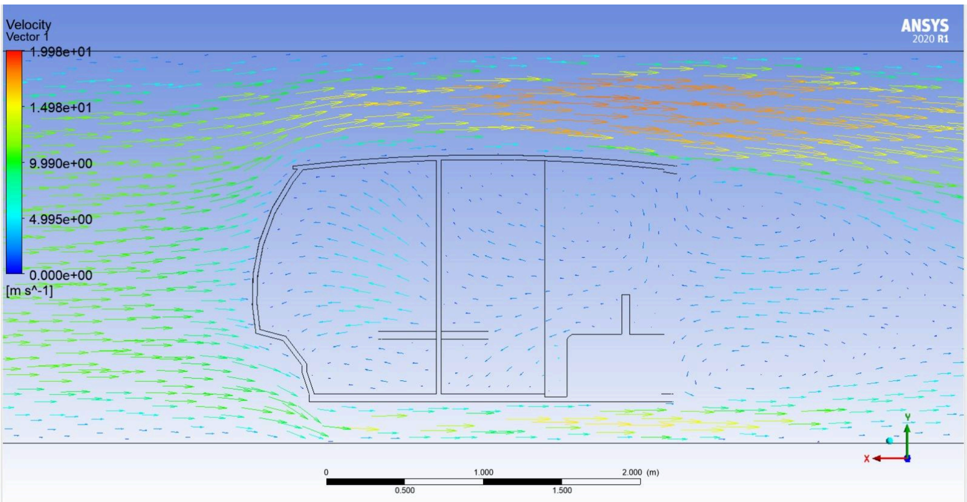
4.1.3 CFD Analysis of Wind Flow Around an Auto Rickshaw

ANSYS Fluent was used to execute a Computational Fluid Dynamics (CFD) simulation in order to evaluate the aerodynamic performance and wind flow characteristics surrounding an auto rickshaw. A computational area measuring 8 meters in length, 2 meters in width, and 2.5 meters in height encircled the auto rickshaw model. The enclosure's design aimed to efficiently capture the behavior of wind flow surrounding the vehicle.

Simulation Setup

Conventional k-epsilon (k-ε) turbulence model with conventional wall functions was used to set up a viscous model for the simulation. The rickshaw's front was the target of the 40 km/h (or 11.11 m/s) input wind velocity, while the outlet was configured to let unrestricted flow out of the vehicle. In order to take into account the effects of natural gravitation, the gravitational acceleration was adjusted to 9.82 ms^{-2} in the negative y-direction.

To ensure a realistic depiction of the wind flow surrounding the vehicle, the auto rickshaw body was removed from the enclosure using a boolean operation. By generating the mesh with default values, the trade-off between computational efficiency and solution correctness was balanced.



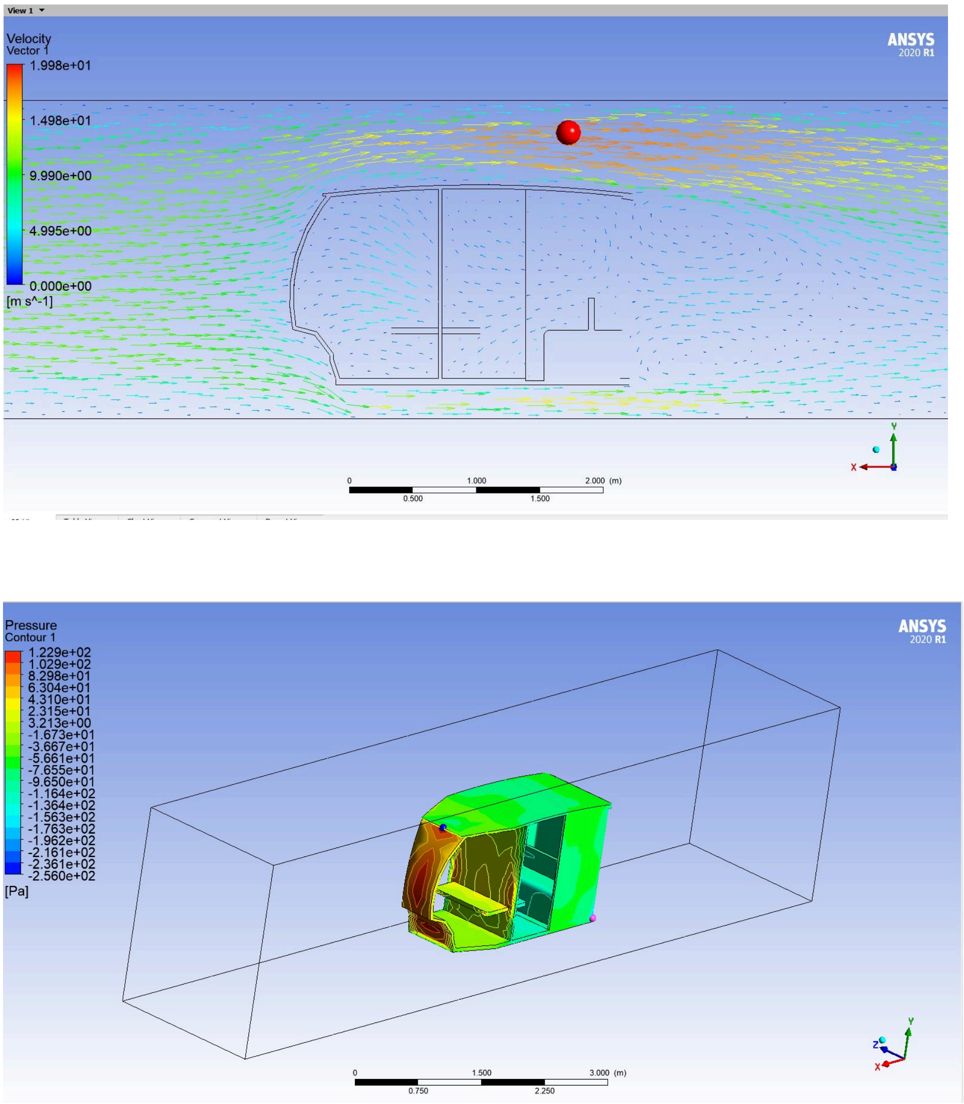


Fig 4.4: CFD Simulation on auto rickshaw a)wind pressure around the auto rickshaw,b)highest velocity point and c) pressure contour simulation

Comprehensive insights into the auto rickshaw's aerodynamic performance were obtained from the simulation. The pressure distribution on the rickshaw body, velocity curves, drag force, and drag coefficient were among the important findings.

- **Drag Force and Drag Coefficient:** The drag coefficient (Cd) was computed to be 0.52180171 and the drag force operating on the auto rickshaw was determined to be 197.28653 N. These figures show the aerodynamic resistance the car will encounter at the given wind speed.

- **Velocity Contours and Streamlines:** The streamline plots and velocity contour showed the rickshaw's surrounding wind flow patterns. Because of the shape and direction of the vehicle, the maximum wind velocity was detected at the top-back of the vehicle body, indicating a significant acceleration of airflow in this area.

- **Pressure Contours:** There were places of high and low pressure visible on the map of the pressure distribution on the rickshaw body. As is common with flow separation events, the front-facing surfaces were under more pressure, while the sides and back were under lower pressure zones.

The CFD study showed that different wind pressures and velocities—which are essential for maximizing energy capture—would probably be experienced by the diffuser-augmented wind turbine when it is integrated into the auto rickshaw. The top-back of the rickshaw's body, which has been identified as a high-velocity region, may be the best site to put turbines in order to harness wind energy to the fullest.

The study's findings lay the groundwork for future development of the wind turbine design that takes the vehicle's aerodynamic interactions with the wind flow into account. The velocity and pressure distributions provide crucial information that can be used to improve the diffuser and blade designs of the turbine, increasing its overall efficiency and performance under real-world conditions.

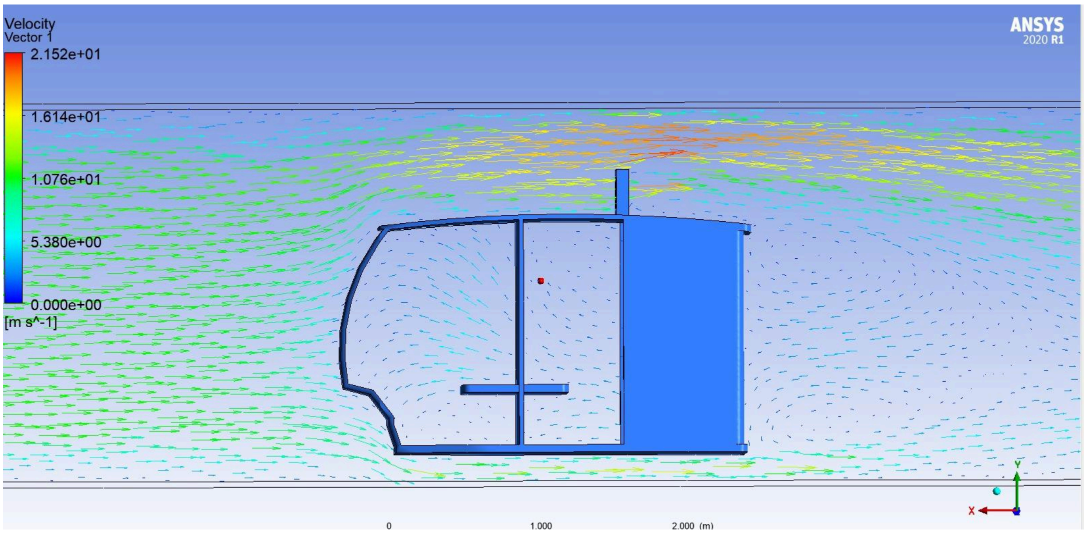
The aerodynamic environment surrounding an auto rickshaw has been effectively defined by this CFD simulation, pointing out important locations for the integration of wind turbines. The derived drag force and coefficient, in addition to comprehensive flow visualizations, provide crucial information for the continuous development of wind-energy-based sustainable mobility solutions. Urban transportation scenarios will benefit from practical and efficient implementations made possible by more empirical testing and optimization based on these discoveries.

4.1.4 CFD Analysis of Wind Flow Around Auto Rickshaw with DAWT

A second analysis was carried out after the first CFD simulation to evaluate the effects of including a Diffuser Augmented Wind Turbine (DAWT) in the auto rickshaw's design. Measuring 300 mm in length, 300 mm in width, and 80 mm in height, the DAWT was carefully positioned at the site of the highest wind velocity found in the earlier simulation. This section describes how the turbine integration has affected flow characteristics and aerodynamic performance.

Simulation Setup

In order to assure comparability and consistency, the setup parameters were identical to those from the first simulation. Standard wall functions and the Standard k-epsilon (k-ε) turbulence model were used. The prescribed gravity was 9.82 m/s² in the negative y-direction, and the inlet wind velocity was set at 40 km/h. Using a boolean operation, the auto rickshaw model, including the DAWT, was removed from the enclosure. To strike a balance between computational economy and solution correctness, default mesh settings were employed.



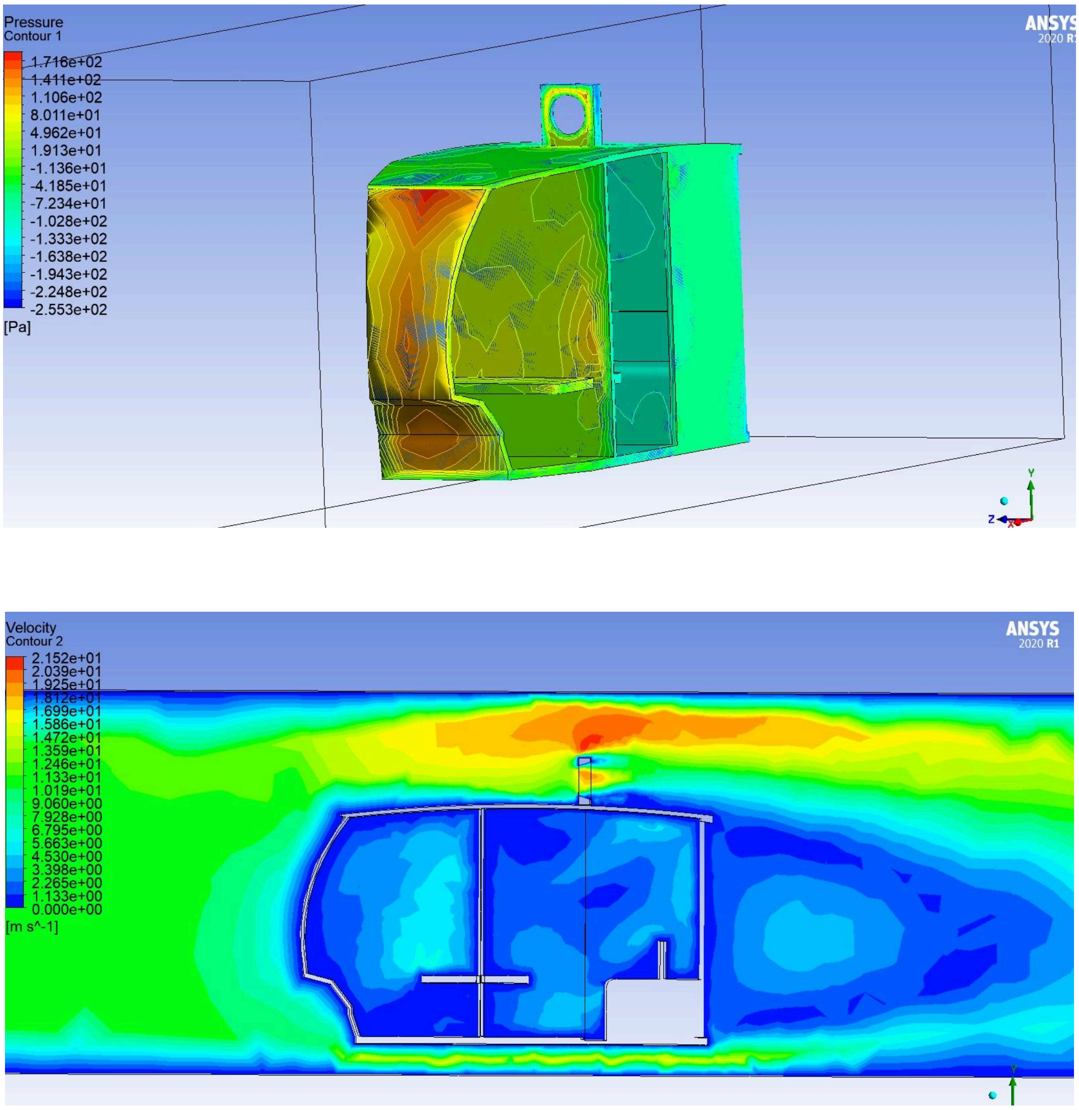


Fig 4.5: Simulations with the wind turbivelocity vector , b)pressure contour and c)velocity contour

Important flow characteristics and aerodynamic parameters were calculated with an emphasis on how the DAWT affected the auto rickshaw's overall performance.

- **Drag Force and Drag Coefficient:** The incorporation of the DAWT led to a 0.69872106 drag coefficient and an increase in drag force of 264.17737 N. These numbers show that the turbine's presence increases aerodynamic resistance, which affects the airflow surrounding the car.
- **Velocity Contours and Streamlines:** The DAWT caused notable alterations in the airflow patterns surrounding the rickshaw, as evidenced by the velocity contours and streamlines. Higher velocity gradients and altered streamline trajectories were

brought up by the turbine, especially in the area surrounding the rickshaw's top back.

- **Pressure Contours:** The impact of the turbine on the aerodynamic profile of the vehicle was demonstrated by the pressure distribution on the rickshaw body, which exhibited increased pressure upstream of the DAWT and decreased pressure downstream.

Both drag force and drag coefficient increased noticeably when the DAWT was integrated at the ideal high-velocity site. The turbine's larger surface area and its impact on the surrounding airflow are the causes of the extra aerodynamic resistance. The modified pressure and velocity distributions demonstrate how the turbine affects the vehicle's aerodynamic performance. In order to maximize energy capture, the DAWT's presence increased local wind speeds around the turbine blades. To guarantee a balance between energy generation and vehicle performance, the increased aerodynamic resistance must be taken into account during the system's overall design and optimization process.

The placement decision was supported by the velocity contour figure, which showed that the DAWT was in the center of the highest wind velocities. According to the pressure contour map, the DAWT's front-facing surfaces saw higher pressures while its rear-facing surfaces saw lower pressures. These findings are consistent with the processes of flow separation and reattachment.

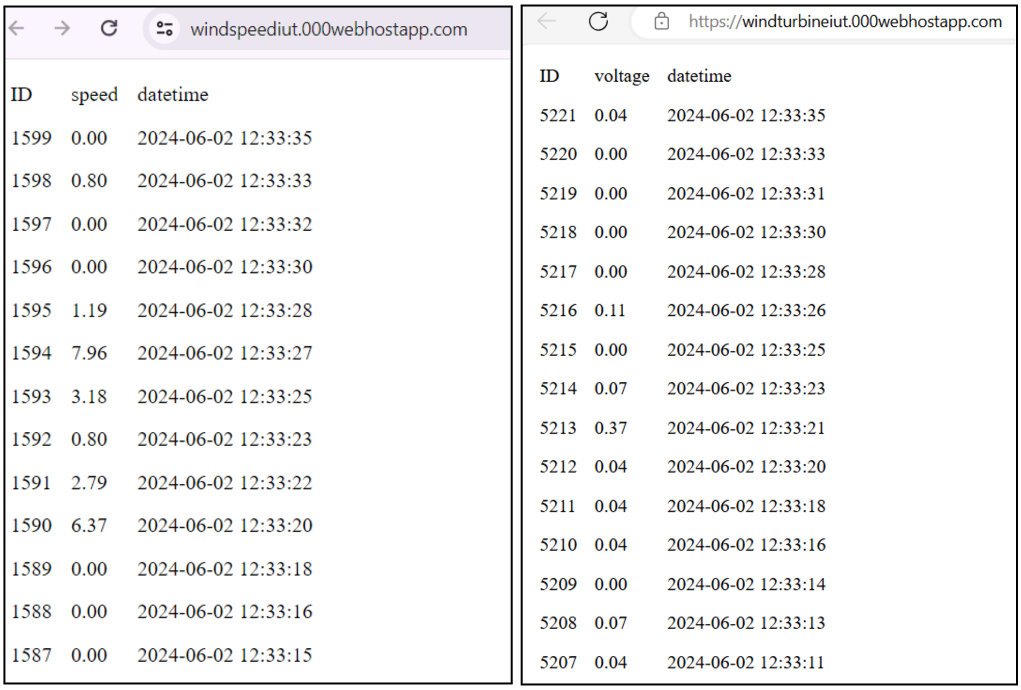
The aerodynamic properties of an auto rickshaw are significantly affected by the integration of a DAWT, as this updated CFD analysis shows. The results highlight how crucial careful planning and location are to efficiently harvest wind energy while controlling rising aerodynamic resistance. These realizations offer a vital starting point for creating workable and effective wind energy systems for environmentally friendly urban transportation. The complete realization of DAWT integration in urban transportation solutions necessitates additional empirical validation and optimization grounded in these findings.

4.2 Data Collection & Processing

The DAWT (Diffuser Augmented Wind Turbine) experimental setup's incorporation of IoT technologies made it easier to gather real-time data on voltage generation and wind velocity. A number of crucial procedures were involved in managing and getting this data ready for analysis, including data extraction, sorting, alignment, error correction, and consolidation into a single Excel sheet. The procedure in full is explained below.

4.2.1 Data Extraction from IoT Databases

Data extraction from two different IoT databases was required in the first stage. While the other database recorded the voltage produced by the turbine along with its timestamps, the first database had measurements of wind velocity in kilometers per hour along with the relevant timestamps. ESP8266 microcontrollers were used to gather the data, and they then sent the information to cloud-based databases.



windspeediut.000webhostapp.com

ID	speed	datetime
1599	0.00	2024-06-02 12:33:35
1598	0.80	2024-06-02 12:33:33
1597	0.00	2024-06-02 12:33:32
1596	0.00	2024-06-02 12:33:30
1595	1.19	2024-06-02 12:33:28
1594	7.96	2024-06-02 12:33:27
1593	3.18	2024-06-02 12:33:25
1592	0.80	2024-06-02 12:33:23
1591	2.79	2024-06-02 12:33:22
1590	6.37	2024-06-02 12:33:20
1589	0.00	2024-06-02 12:33:18
1588	0.00	2024-06-02 12:33:16
1587	0.00	2024-06-02 12:33:15

https://windturbineiut.000webhostapp.com

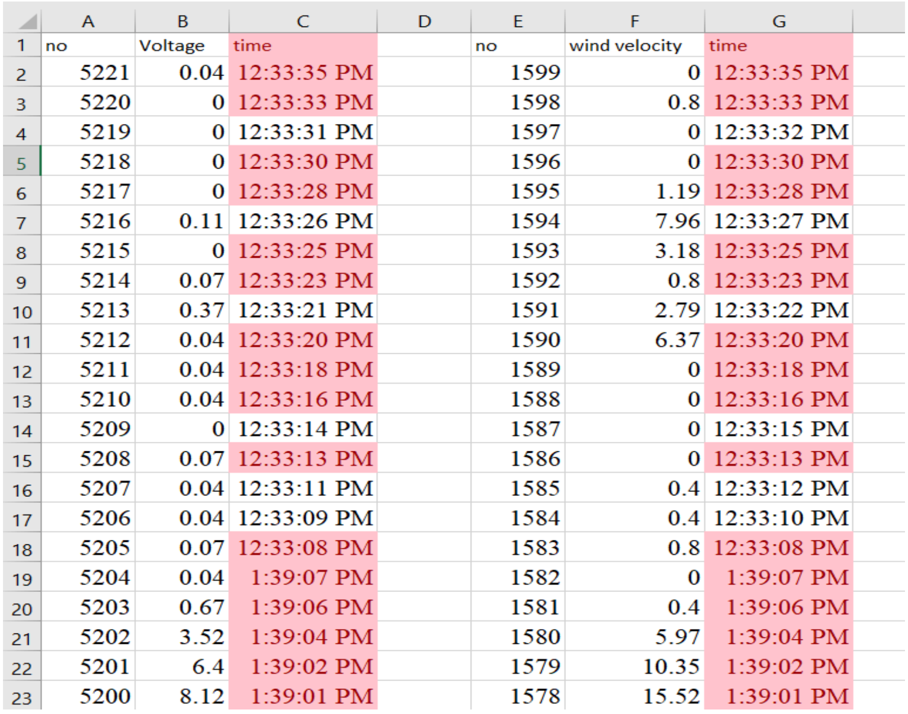
ID	voltage	datetime
5221	0.04	2024-06-02 12:33:35
5220	0.00	2024-06-02 12:33:33
5219	0.00	2024-06-02 12:33:31
5218	0.00	2024-06-02 12:33:30
5217	0.00	2024-06-02 12:33:28
5216	0.11	2024-06-02 12:33:26
5215	0.00	2024-06-02 12:33:25
5214	0.07	2024-06-02 12:33:23
5213	0.37	2024-06-02 12:33:21
5212	0.04	2024-06-02 12:33:20
5211	0.04	2024-06-02 12:33:18
5210	0.04	2024-06-02 12:33:16
5209	0.00	2024-06-02 12:33:14
5208	0.07	2024-06-02 12:33:13
5207	0.04	2024-06-02 12:33:11

Fig 4.6: IoT Database for measuring variables

(a) Wind Velocity, (b) Voltage

4.2.2 Excel Sheet Generation

The information was moved to separate Excel sheets after it was taken out of the databases. One sheet had the data on wind velocity, while another contained the data on voltage. Every sheet had columns with the matching timestamps and the appropriate measurement (voltage or wind speed).



	A	B	C	D	E	F	G
1	no	Voltage	time		no	wind velocity	time
2	5221	0.04	12:33:35 PM		1599	0	12:33:35 PM
3	5220	0	12:33:33 PM		1598	0.8	12:33:33 PM
4	5219	0	12:33:31 PM		1597	0	12:33:32 PM
5	5218	0	12:33:30 PM		1596	0	12:33:30 PM
6	5217	0	12:33:28 PM		1595	1.19	12:33:28 PM
7	5216	0.11	12:33:26 PM		1594	7.96	12:33:27 PM
8	5215	0	12:33:25 PM		1593	3.18	12:33:25 PM
9	5214	0.07	12:33:23 PM		1592	0.8	12:33:23 PM
10	5213	0.37	12:33:21 PM		1591	2.79	12:33:22 PM
11	5212	0.04	12:33:20 PM		1590	6.37	12:33:20 PM
12	5211	0.04	12:33:18 PM		1589	0	12:33:18 PM
13	5210	0.04	12:33:16 PM		1588	0	12:33:16 PM
14	5209	0	12:33:14 PM		1587	0	12:33:15 PM
15	5208	0.07	12:33:13 PM		1586	0	12:33:13 PM
16	5207	0.04	12:33:11 PM		1585	0.4	12:33:12 PM
17	5206	0.04	12:33:09 PM		1584	0.4	12:33:10 PM
18	5205	0.07	12:33:08 PM		1583	0.8	12:33:08 PM
19	5204	0.04	1:39:07 PM		1582	0	1:39:07 PM
20	5203	0.67	1:39:06 PM		1581	0.4	1:39:06 PM
21	5202	3.52	1:39:04 PM		1580	5.97	1:39:04 PM
22	5201	6.4	1:39:02 PM		1579	10.35	1:39:02 PM
23	5200	8.12	1:39:01 PM		1578	15.52	1:39:01 PM

Fig 4.7: Data Sorting in MS Excel

4.2.3 Data Sorting and Alignment

It was essential to align the wind velocity and voltage data according to their timestamps in order to provide effective analysis. The actions listed below were carried out:

- **Sorting by Time:** The timestamp column on both Excel sheets was used to arrange the data in ascending order. This made sure that the data points were organized chronologically, which made matching measures easier to align.
- **Matching Timestamps:** Next, a thorough examination of the sorted data was conducted to find timestamps that matched between the two sheets. In order to align the data points where the times matched, the timestamps had to be manually or programmatically compared.

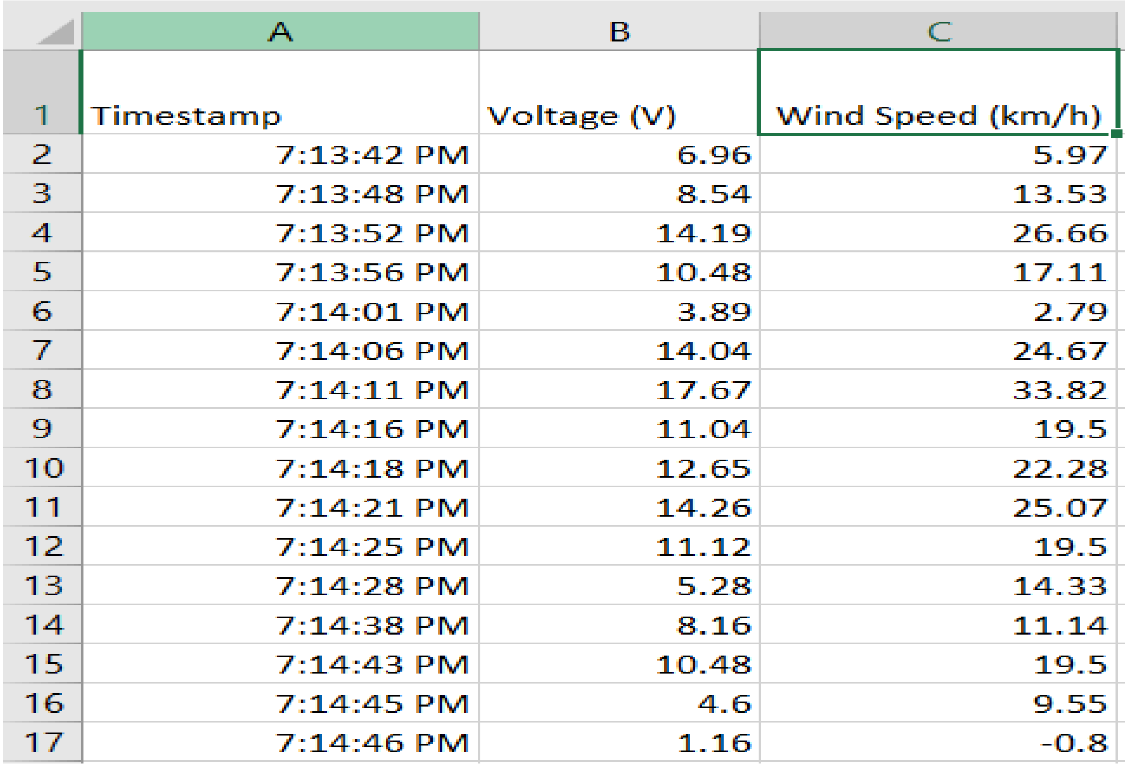
4.2.4 Error Elimination and Time Variation Reduction

Discrepancies including incorrect or missing data points were found and fixed throughout the alignment procedure. This included:

- **Error Elimination:** Taking care of any discrepancies in the timestamps and eliminating any data points that have obvious incorrect values (such as negative wind speeds or voltages).
- **Time Variation Reduction**: To minimize time variation in situations when the timestamps did not line up exactly, a tolerance range was set. Data points that were within a certain temporal range (such as ±1 second) were deemed matching and then aligned.

4.2.5 Consolidation into a Single Excel Sheet

Consolidating the wind velocity and voltage data into a single Excel sheet was the last step after the data had been sorted, aligned, and cleaned. Three columns made up the combined sheet: voltage (V), wind speed (km/h), and the associated timestamp. A thorough understanding of the link between wind speed and electricity generation over time was made possible by this one dataset.



	A	B	C
1	Timestamp	Voltage (V)	Wind Speed (km/h)
2	7:13:42 PM	6.96	5.97
3	7:13:48 PM	8.54	13.53
4	7:13:52 PM	14.19	26.66
5	7:13:56 PM	10.48	17.11
6	7:14:01 PM	3.89	2.79
7	7:14:06 PM	14.04	24.67
8	7:14:11 PM	17.67	33.82
9	7:14:16 PM	11.04	19.5
10	7:14:18 PM	12.65	22.28
11	7:14:21 PM	14.26	25.07
12	7:14:25 PM	11.12	19.5
13	7:14:28 PM	5.28	14.33
14	7:14:38 PM	8.16	11.14
15	7:14:43 PM	10.48	19.5
16	7:14:45 PM	4.6	9.55
17	7:14:46 PM	1.16	-0.8

Fig 4.8: Completion of Data Sorting

The accuracy of the final dataset was guaranteed by the procedures of data extraction, sorting, alignment, error correction, and consolidation, which prepared it for in-depth analysis. The generated Excel sheet made it easier to assess how well the DAWT system worked and provided insights into the turbine's efficacy and efficiency in different wind scenarios.

4.3 Experimental Data Analysis and Visualization

4.3.1 Scatter Diagram Generation

An experimental setup was made in order to assess the effectiveness of the Diffuser Augmented Wind Turbine (DAWT) mounted on an auto rickshaw. An Internet of Things (IoT) device was used to gather data when the DAWT turbine model was fixed atop the auto rickshaw. The wind speed (in km/h) and the corresponding voltage produced by the turbine over time were among the data gathered.

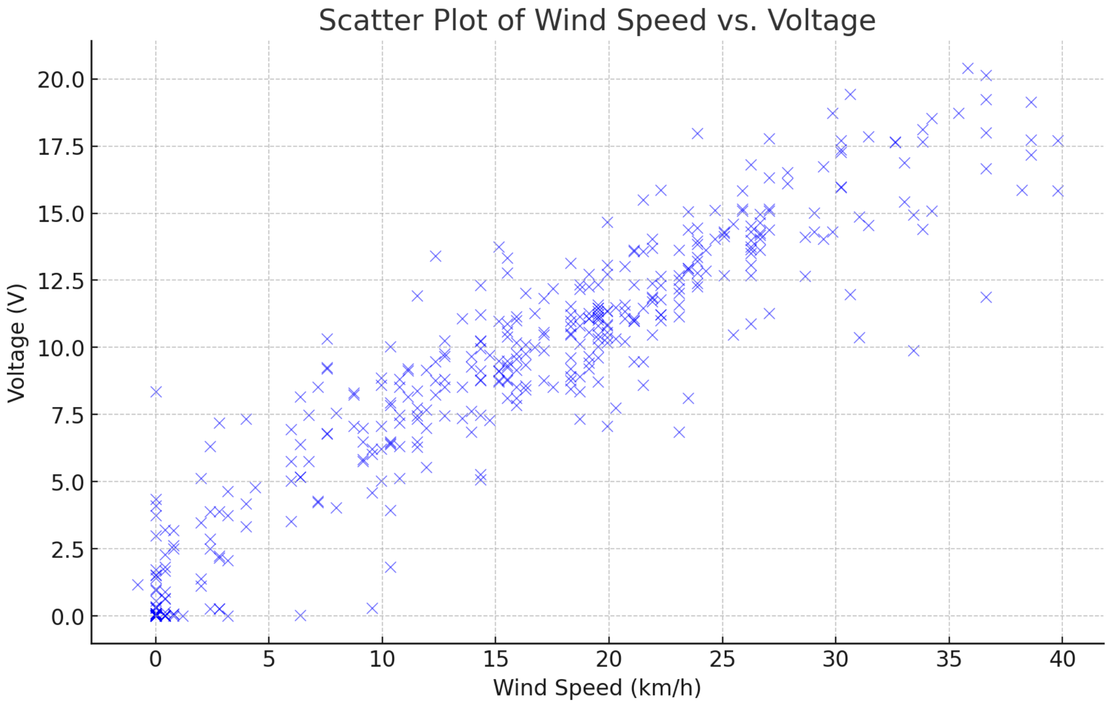


Fig 4.9: Scatter diagram of the wind turbine data

4.3.2 Data Collection

In order to gather data, sensors and Internet of Things devices were used to record voltage output and wind speed at predetermined intervals. A CSV file containing the recorded data was saved for later examination. Important variables gathered were:

- Wind Speed (km/h): The wind speed at which the turbine is affected.
- Voltage (V): The power that the turbine produces.

4.3.3 Data Visualization

A scatter plot was made to show the relationship between wind speed and voltage generated. The following are the stages that go into creating the scatter plot:

- **Data Loading:** The Python pandas package was used to import the data from the CSV file. This rendered it simple to manipulate and analyze the dataset.
- **Data Inspection:** To ascertain the structure of the dataset and guarantee data integrity, the first few rows were examined.
- **Plotting:** To show the link between wind speed and voltage, a scatter plot was created in Python using the matplotlib tool. The specifics listed below were used:
  - Figure Setup: To provide the best possible display, a figure measuring 10 by 6 inches was prepared.
  - Scatter Plot: The voltage (V) and wind speed (km/h) were plotted on the x and y axes, respectively. To better visualize overlapping dots, each data point was represented as a blue dot with a small transparency (alpha = 0.6).
  - Plot Personalization: A title ("Scatter Plot of Wind Speed vs. Voltage") and named axes ("Voltage (V)" for the y-axis and "Wind Speed (km/h)" for the x-axis were added to the plot. To make it easier to read, a grid was added.
- **Interpretation of the Results:** The scatter plot gave a clear visual picture of how variations in wind speed affected the DAWT turbine's voltage output. For the purpose of finding patterns and connections in the experimental data, this display was essential.

Through the process of data visualization, the performance of the DAWT turbine was thoroughly examined, which improved comprehension and allowed for the optimization of the turbine design using actual trial data.

4.3.4 Graph Visualization and Smoothing Process

A system that uses the Internet of Things (IoT) was used to gather data on wind speed and voltage generated in order to assess the operation of the Diffuser Augmented Wind Turbine (DAWT) installed on an auto rickshaw. The goal was to create a highly smoothed and sorted line graph with discrete intervals for wind speed, based on an initial scatter plot, that would be easy to understand and analyze. The specific steps are outlined in the following order:

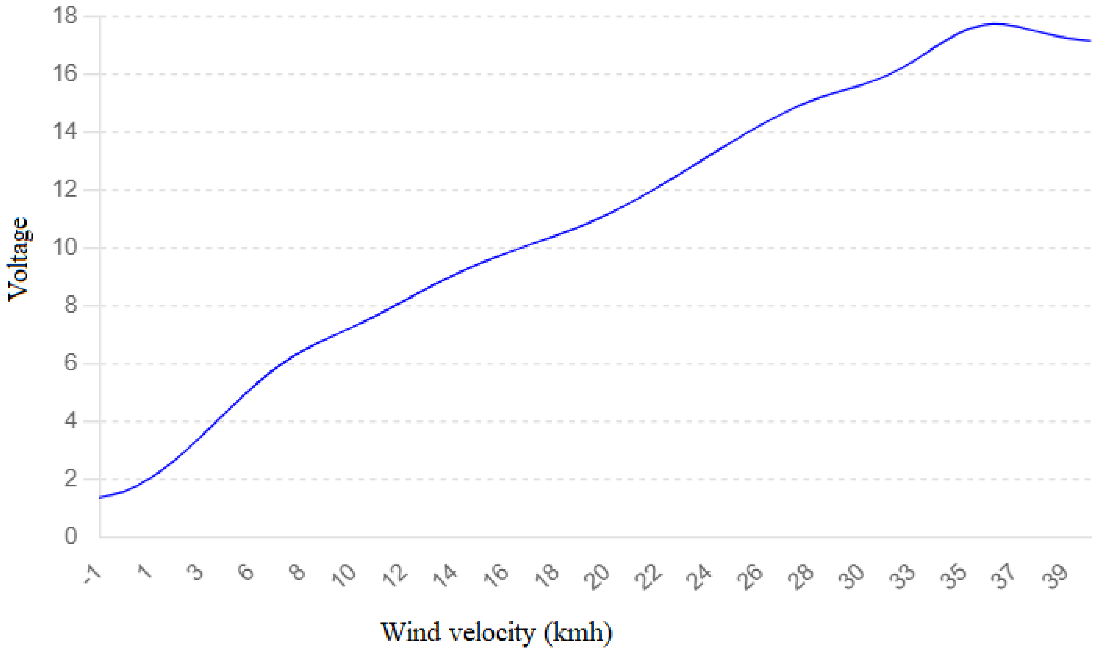


Fig 4.10 : Final graph after smoothing

Data Smoothing and Outlier Removal

To show the link between wind speed and voltage, a scatter plot was first created as part of the data visualization process. The voltage (V) and wind speed (km/h) were plotted on the y- and x-axes, respectively, using the Python "matplotlib" package. Each data point was shown as "alpha=0.6", a blue dot with a small amount of transparency. The data distribution was first seen in this scatter plot, albeit there were notable outliers and swings.

Data Smoothing and Outlier Removal

The following phase involved smoothing the data and removing outliers to improve the visualization's clarity. The Interquartile Range (IQR) approach was used to identify and eliminate outliers; values outside of 1.5 times the IQR from the first (Q1) and third quartiles (Q3) were excluded. Pandas utilities were utilized for this: "quantile()" was used to compute Q1 and Q3, and boolean indexing was used to filter the data.

Initial smoothing was achieved using a rolling mean with a window size of 15, applied to the voltage data. Using the "rolling()" and "mean()" functions in pandas, this method helped minimize short-term oscillations and emphasize the general trend. In spite of this, there was still some noise visible in the resulting line graph.

Binning and Averaging

To establish discrete intervals, the wind speed data was rounded to the nearest natural integer in the last stage. The pandas "round()" method was used to do this binning procedure. The "groupby()" and "mean()" functions in pandas were then used to determine the mean voltage for each bin after the data had been grouped by these rounded wind speed numbers. This procedure made sure that every wind speed value had an average voltage that matched it, which made trend analysis easier to understand.

Sorting and Final Plotting

The "sort_values()" method was used to sort the binned data according to wind speed in ascending order. This made the graph easier to read and understand by ensuring that the x-axis values climbed gradually from 0 to 1.

"matplotlib" was used to create the final line graph. On the x-axis, the wind speed (km/h) was plotted, and on the y-axis, the highly smoothed voltage (V). To improve readability, the graph was altered with grids, axis labels, and titles. Additionally, the "xticks()" function was used to set the x-axis to display natural number intervals.

Result Interpretation

The relationship between wind speed and voltage produced by the DAWT turbine was clearly and accurately visualized in the fully smoothed and sorted line graph that was the end product. This final depiction made it easier to spot patterns and trends in the trial data, which helped with the turbine design's assessment and improvement.

This thorough process made sure that a graph that was easy to understand was produced, which included important information about the DAWT turbine's performance and possible uses in environmentally friendly transportation solutions.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Many important inferences can be made from the thorough examination of the CFD simulations, the experimental data gathering, and the ensuing data processing. These findings emphasize the advantages and disadvantages of this novel arrangement while offering insightful information about the effectiveness of the DAWT turbine combined with an auto rickshaw.

The power coefficient of 0.613 obtained from the calculations suggests an efficiency that surpasses the theoretical maximum (Betz limit) of 59.3%. This indicates a discrepancy in the computation or measurement procedure, as it is impossible for a rotor to surpass this threshold. Additional examination and adjustment are required to acquire precise efficiency numbers for the rotor design.

The turbine produced approximately 15V under trial conditions, with a wind speed of 30 km/h and an efficiency of 51.2%. This efficiency level is within a small wind turbine's practical range, indicating that the turbine can produce a significant amount of power under practical working conditions.

The drag force of the auto rickshaw increased significantly from 197.28653 N to 264.17737 N after the turbine was integrated on top of the vehicle. This significant increase highlights the effect the turbine's location has on aerodynamics and the necessity of giving drag forces considerable thought throughout the design and implementation of such systems.

Another 557.35 W of power was lost as a result of the turbine's positioning, which increased drag force. This significant power loss emphasizes how crucial it is to take aerodynamic drag into account when calculating overall energy efficiency. Optimizing the performance and viability of wind energy systems linked with moving vehicles requires mitigating these losses.

The integrated system, the auto rickshaw body, and the blade's aerodynamic behavior were all thoroughly explained by the CFD simulations. Understanding the flow patterns, pressure distributions, and resulting forces acting on the system through these simulations was crucial for informing design modifications and optimization techniques.

It was successful to collect data in real-time using IoT technology, which allowed for precise measurements of voltage generation and wind speed. Sorting, aligning, and eliminating errors were among the data processing stages that followed, ensuring a clean and trustworthy dataset for analysis.

The relationship between wind speed and voltage production was made easier to see by creating and smoothing graphs from the data that was gathered. The interpretation of the turbine's performance characteristics and the identification of regions in need of additional improvement were made possible by this representation.

The potential of mobile wind energy systems was proved by the combination of the DAWT turbine with the auto rickshaw. To maximize efficiency and reduce negative effects, more design and location refinement is necessary, as evidenced by the increasing aerodynamic drag and related power losses.

Together, these findings show that DAWT turbines have a bright future in the production of sustainable energy, but they also stress how crucial it is to solve aerodynamic issues in order to maximize efficiency and performance.

5.2 Future Scopes

The "Integration of Diffuser Augmented Wind Turbine on Automobiles for Power Generation" project has broad and diverse future scopes that promise major improvements in technology and its applications. The aforementioned prospective advancements seek to augment the efficacy, expandability, and influence of the undertaking, hence facilitating the wider integration of sustainable energy remedies in urban conveyance. Future research and innovation should focus on the following areas:

1. **Utilization of innovative Materials**: Investigating how to increase production efficiency and lower costs by using lightweight, durable, and innovative materials for diffuser structures and turbine blades.
2. **Integration with Electric Vehicles**: To increase the influence on sustainable urban

transportation, extending the application to include various electric vehicle types, such as automobiles, buses, and trucks.

3. **Improved Computational Models:** Creating more complex CFD models using machine learning techniques and real-time data to forecast and maximize performance in a range of environmental scenarios.
4. **Techno-Economic Feasibility Studies**: Performing thorough techno-economic analyses to determine whether deploying this technology on a bigger scale, with possible commercial applications, would be cost-effective and scalable**.**
5. **Energy Storage Solutions:** Including energy storage devices, such supercapacitors or sophisticated batteries, to store the energy produced by wind turbines and enhance the cars' overall energy management.

6. **Urban Infrastructure Adaptation:** To encourage a wider use of renewable energy solutions, research is being done on how these systems may be integrated into urban infrastructure, such as public transit networks or charging stations.
7. **Developing laws and Policies:** Working with legislators to create incentives and laws that will support the use of wind energy systems in urban transportation.
8. **Environmental Impact Assessment**:Comprehensive environmental impact assessments should be carried out in order to identify and lessen any possible drawbacks from the widespread use of these technologies.
9. **User Experience and Safety:** Enhancing the design to make the system more user-friendly, guaranteeing the system's dependability and safety under a range of operating circumstances, and attending to any end-user ergonomic and aesthetic concerns.
10. **Partnerships and Collaborations**: Establishing partnerships with government agencies, business partners, and academic institutions in order to advance research, development, and deployment activities while utilizing a multidisciplinary approach to innovation and sustainability.

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