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DESIGN & FLOW ANALYSIS OF SUBSONIC WIND TUNNEL

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ABSTRACT

A wind tunnel is an essential tool in aerodynamic research, used to study the effects of air movement over solid objects. Initially developed for analyzing vehicles, particularly airplanes, in free flight, wind tunnels help assess aerodynamics and measure drag and downforce on airfoils. A typical wind tunnel consists of a contraction cone, test section, and diffuser, equipped with necessary instrumentation for measuring aerodynamic forces. Our project focuses on utilizing a hand-fabricated wind tunnel to test the aerodynamics of scaled models and calculate their drag. Considering aerodynamics in vehicle design is crucial today, as it enhances efficiency and reduces fuel consumption. This hand-fabricated wind tunnel simplifies aerodynamic testing and drag calculation for scaled models, thereby streamlining the design and production process.

1. INTRODUCTION

A wind tunnel is a vital tool in aerodynamic research, used to analyze the effects of air movement over solid objects. It consists of a closed tubular passage where the test object is positioned at the center. A powerful fan system generates airflow, with straightening vanes ensuring smooth and uniform flow.
To measure aerodynamic forces, the test object is equipped with a sensitive balance, or airflow visualization techniques such as smoke injection may be used to observe flow patterns around the object. While full-scale aircraft and vehicles are sometimes tested in large wind tunnels, these facilities are costly to operate, and many of their functions have been replaced by computer modeling. Beyond vehicles, wind tunnels are also employed to study airflow around large structures like bridges and office buildings.
Wind tunnels were initially developed to study vehicles, primarily airplanes, in free flight. The concept was based on reversing the usual scenario: instead of an aircraft moving through stationary air, air would be moved past a stationary aircraft, allowing researchers to observe aerodynamic forces in action. This setup enabled precise measurement of forces acting on the aircraft.

Over time, wind tunnel testing expanded beyond aviation. As buildings grew taller, it became necessary to study the impact of wind on large structures to ensure their stability. These studies informed building codes by determining the forces that structures must withstand. Later, wind tunnels were applied to automobiles, not just to assess aerodynamic forces but to improve efficiency by reducing the power required for movement. Unlike in real-world conditions where the road moves relative to the vehicle, wind tunnel tests involve stationary road surfaces while air moves past the vehicle. Some wind tunnels incorporate moving belts beneath test vehicles to better simulate real-world conditions.

Air velocity and pressure within wind tunnels are measured using Bernoulli’s principle, dynamic and static pressure readings, and temperature variations in compressible flow. Airflow direction around a model can be visualized using yarn tufts, smoke trails, or liquid bubbles. Aerodynamic forces are typically measured using beam balances attached to the test model with beams, strings, or cables.

Pressure distribution on a model has traditionally been measured using small drilled holes connected to multi-tube manometers. More advanced techniques, such as pressure-sensitive paint and ultra-miniaturized sensor belts, now provide real-time pressure mapping. Another method, known as wake survey, involves taking pressure readings downstream of the model using pitot tubes or multiple-tube manometers.

It is important to note that aerodynamic properties do not scale linearly, meaning test results from scaled-down models may not directly translate to full-scale designs. Aerodynamics, derived from the Greek words aer (air) and dynamics (motion), is a subfield of fluid dynamics focused on the interaction between air and solid objects, such as aircraft wings. While aerodynamics is often associated with gas dynamics, the latter applies to all gases, not just air.

The formal study of aerodynamics began in the 18th century, with early research focused on achieving heavier-than-air flight, culminating in the Wright brothers' first powered flight in 1903. Since then, mathematical analysis, empirical studies, wind tunnel experimentation, and computer simulations have advanced aerodynamic understanding. Recent research emphasizes compressible flow, turbulence, and boundary layers, with computational methods playing an increasingly significant role.

In fluid dynamics, drag (or air resistance) is the force opposing an object's motion relative to a surrounding fluid. Unlike dry friction, which remains nearly constant regardless of velocity, drag force varies with velocity—proportionally in laminar flow and as the square of velocity in turbulent flow. While drag ultimately results from viscous friction, turbulent drag is largely independent of viscosity.

2. LITERATURE

Wind tunnel testing has been a crucial tool in aerodynamic research, providing insights into airflow behavior and aerodynamic forces acting on different objects. Anderson (2001), in Fundamentals of Aerodynamics, provides a comprehensive overview of wind tunnels, explaining their historical development, working principles, and experimental techniques such as smoke visualization and force measurements. This work highlights how wind tunnels help optimize vehicle and aircraft designs by reducing drag and enhancing aerodynamic efficiency. Similarly, Tamura (2008), in Towards Practical Use of LES in Wind Engineering, emphasizes the significance of wind tunnels in studying wind loads on tall buildings, bridges, and large structures. The study compares experimental wind tunnel data with computational fluid dynamics (CFD) simulations, underscoring the role of wind tunnels in refining building codes and improving architectural stability against dynamic wind effects.

The application of wind tunnels extends to the automotive industry, as discussed by Hucho (1998) in Aerodynamics of Road Vehicles. This work explores how modern wind tunnels incorporate moving belts to simulate real-world road conditions more accurately, leading to advancements in drag reduction and fuel efficiency. It also highlights techniques such as underbody airflow management and active aerodynamics, which play a critical role in vehicle design. In addition to automotive applications, pressure measurement techniques in wind tunnels have evolved significantly. Bryer and Pankhurst (1971), in Pressure Probes for Fluid Measurements, compare traditional multi-tube manometers with advanced pressure-sensitive paint (PSP) and sensor belts. The study discusses wake survey techniques and improvements in measurement precision, particularly in subsonic and supersonic wind tunnels.

While wind tunnel testing remains a fundamental tool, computational methods are increasingly being used as an alternative. Spalart (2009), in Detached-Eddy Simulation and Related Methods, evaluates the role of CFD in aerodynamic research. Although CFD offers cost advantages and detailed flow visualization, it has limitations in accurately capturing turbulence and boundary layer interactions. The study concludes that while CFD complements wind tunnel experiments, physical testing remains indispensable for validating computational results, especially in complex aerodynamic scenarios. Overall, wind tunnel testing continues to be an essential method in aerodynamics, with advancements in technology improving both experimental and computational approaches to studying airflow behavior.

3. RESULTS AND DISCUSSION

3.1. Smoke

Smoke is the most common method of flow field visualization. The smoke can be produced in a number of ways. Burning damp straw, rotten wood and tobacco to produce smoke is generally unsatisfactory, even though historic work was accomplished with smoke from such materials. The same is true of pyrotechnic smoke devices. Chemical methods of producing include both titanium tetrachloride and tin tetrachloride, which produce smoke when brought into contact with moist air. Another method of producing some is from the heated wire. When a large current is sent through a thin heating coil wire the wire gets hot enough to evaporate liquid paraffin oil smeared on it. When the paraffin evaporates, smoke starts emitting from the wire. The smoke visualization is move vivid in this type of system shown in Figure 1 and 2.

Figure 1. Smoke moves at zero angle of attack

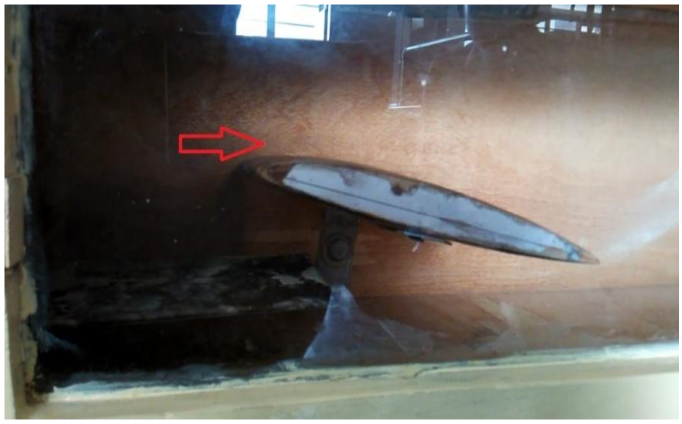

Figure 2. Smoke moves at 25º angle of attack

4. CONCLUSION

4.1. Purpose

- The project was an attempt to achieve two major objectives; the first was the design and fabrication of the wind tunnel and the second being study airflow on aerofoil. Hence the project was proposed in two parts.

- The experiment was conducted to determine the pressure distribution on NACA 0012 airfoil and the experiment was also to validate the method of testing in wind tunnel. The pressure port method was used to determine the distribution of lift production on the airfoil.

4.2. Expectation

- By looking at the way this smaller model acts in the wind tunnel we get an idea of how a real life size aerofoil structure to be designed. Velocity profile can be studied for the design of cars and aero plane using this model.
- The results obtained from the aerofoil are satisfactory with results co-relating to Bernoulli's theory.
- The expected to find that the airfoil would exhibit constant increasing peak suction with increasing angle of attack.
- The main test for determining the stability of a wind tunnel is the test to see the stability of the hydrodynamic boundary layer throughout the test section.
- We have conducted flow visualization test for the airfoil and during the test and flow remained unseparated throughout the test section.
- For 2hp blower we got the test section length 295 cm, 3m/s velocity, co-efficient of pressure is 0.34-5.3, efficiency 59% ,Reynolds number is 27772.9 .co-efficient of friction is 0.009,discharge is 887.5m3/s and head losses are found.
- When we further moved to the flow visualization of the aerofoil, a smooth visible flow separation was observed. In addition to the stability of the boundary layer, the smoke test also shows the efficiency of the flow straightened section.

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