Design and Fabrication of A Wind Tunnel and A Force Measuring Device

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Abstract- *Most of the typical educational wind tunnels used in Indian colleges are based on pressure sensing methods. In this project we have decided to come up with a different method to measure the aerodynamic lift and drag forces. This paper is based on the design and fabrication process of both wind tunnel and the measuring device. The mechanism has been tested over a range of air velocities with the help of suitable models. Experimental results are obtained by using mechanical and an electrical instrument and are compared with the theoretical value to interpret the errors. One of the major practical benefits resulted from this project is that both mechanical and electrical results are obtained at the same time with the same experimental setup, that allows for direct measurement of aerodynamic forces which was not available previously.*

Keywords- Wind tunnel, test-section, aerofoil, lift, drag, spring, deflection, ultrasonic sensors.

I. INTRODUCTION

A wind tunnel is used as a means to study movement of air flowing past a solid object in aerodynamic studies. In this project we have fabricated a low speed wind tunnel (as it operates at a speed <100 m/s) which can be of either an open circuit or a closed circuit design. We have opted for an open circuit design as it reduces cost, the space requirement and for the ease of construction. The system consists of a contraction cone, test section, diffuser, an axial fan, testing models, a 2D balance setup and an ultra-sonic sensor mechanism [1]. We have used mechanical and an electrical system to approach the results. The setup consists of a spring attached to two perpendicular aluminium bars which in turn are connected to the models to be tested [2]. A completely programmed ultra-sonic sensor is used to measure the displacement of the spring as an electrical approach and a measuring scale is fixed adjacent to the spring to measure the deflection as a mechanical approach. Using the deflection of the spring, the angle at which the aluminium bar shifts and with suitable formulas the aerodynamic forces can be calculated. The complete setup is as shown in the figure.1 and the specific components are identified and discussed in the later sections.

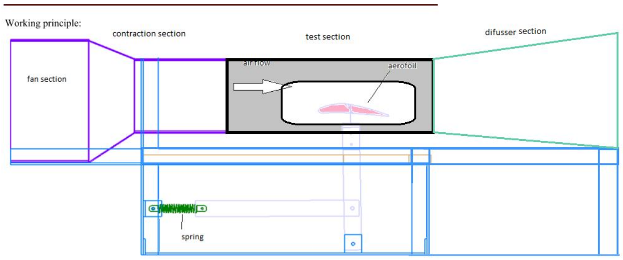


Figure 1.

II. RESEARCH METHODOLOGY

Based on the past research work on the design of wind tunnel, which usually uses pressure distribution on the various points of the test model using pressure sensors and manometer, we have come out with a new design which utilizes a spring balance method to measure the aerodynamic forces economically. Ease of calculation is of major consideration. The experimental wind tunnel that we have fabricated works on the unique method that integrates the 2D balance as a core strategy to resolve the forces into vertical (lift) and horizontal (drag) forces [3]. To measure these forces we are using a spring which has been fabricated after calculating the wind force that is generated by the system (fan) [4].

III. EXPERIMENTAL SETUP

Figure 2.

Contraction cone- The purpose of the contraction is to smoothly accelerate the air entering from the (larger) fan and direct it into the (smaller) test section [5,6]. In the process, turbulence intensity is further reduced, as the overall mean velocity increases while near-instantaneous variations in velocity are little affected. We have used sheet metal while fabricating this part.

Test section-The test section is obviously where the models are placed for testing (here we are testing aerofoil), and thus is the portion of the wind tunnel where the air flow is desired to be most uniform. The ratio of width to height of a test section is generally chosen with the dimension of the testing object as well as the intended purpose of the wind tunnel [7]. We have used acrylic glass to fabricate this part in order to observe the flow of air inside the test section

Axial fan- A fan is required to generate artificial airflow at different velocities [8]. We have used an axial fan with variable speed so that the intended values are obtained for different air velocities.

Specifications-

Diameter of fan wing-12inches
Max. Speed of fan-1400rpm
Voltage-225volts
Current- 5amps
Blade material- aluminium

Diffuser- The purpose of the diffuser is to smoothly decelerate the air exiting the (larger) contraction cone and direct it into the (smaller) test section [9, 10]. In the process, turbulence intensity is further reduced, as the overall mean velocity increases while near-instantaneous variations in velocity are little affected to flow detachment, the maximum semi-opening angle in the diffuser has to be smaller than 40[11].

Testing model- We have used a prototype of an aerofoil as a testing model. The model requires to be of minimum density and volume, hence we have utilized low density wood as a material for the aerofoil. An aerofoil-shaped body moved through a fluid produces an aerodynamic force [12]. The component of this force perpendicular to the direction of motion of fluid is called lift; the component parallel to the direction is called drag.

2D spring balance- It consists of a spring of calculated stiffness. Two aluminium struts are connected in perpendicular to each other, one end to the spring and other to the test model. Due to the varying velocity of air caused by the fan, the test model is deflected from its initial position which causes the elongation of spring. Based on this deflection and the angle made by the aluminium rod the aerodynamic forces are calculated using specific formulas.

Mechanical approach- Deflection of spring is measured using a measuring scale, and the angle is measured with a protractor.

Electrical approach- The initial position and the final position between the transmitter and the receiver is determined using an ultrasonic sensor to measure the deflection. Using the specific formulas the aerodynamic forces are evaluated [13].

Figure 3.

Arduino mega 2560- Arduino is an open-source physical computing platform based on a simple I/O board and a development environment that implements the Processing/Wiring language. The Arduino Mega is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

Ultrasonic sensor HC-SR04- This is the HC-SR04 ultrasonic ranging sensor. This economical sensor provides 2cm to 400cm of non-contact measurement functionality with a ranging accuracy that can reach up to 3mm. Each HC-SR04 module includes an ultrasonic transmitter, a receiver and a control circuit. [14]

Nokia 5110LCD- The Nokia 5110 is a basic graphic LCD screen for lots of applications. It was originally intended for as a cell phone screen. This one is mounted on an easy to solder PCB. It uses the PCD8544 controller, which is the same used in the Nokia 3310 LCD. The PCD8544 is a low power

CMOS LCD controller/driver, designed to drive a graphic display of 48 rows and 84 columns.

IV. CALCULATION

Calculation of spring constant
Spring diameter-0.5mm
Spring pitch-5.3mm
Size factor-2.51
Spring index-10.6
Number of coils in spring-62
Maximum deflection of spring- 11.38mm
Force acting on spring-0.142N
Spring stiffness-128Gpa

Table 1. Observation of spring

Velocity of air (m/s)	Deflection (mm)
4	3
5	5
6	8

Velocity of air (m/s)	Deflection (degree)
4	2^0
5	4^0
6	6^0

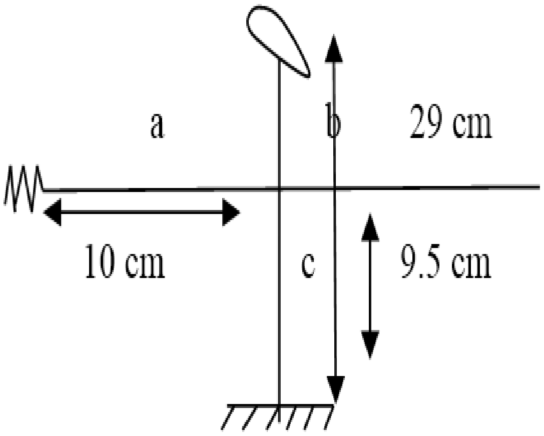


Figure 4.

Formula to calculate lift force

$L = 1/2\ \rho v^2 A\ \ C_L$
$F = (b.c\ .\ \sin\theta\ )/a$

Formula to calculate drag force

$D = 1/2\ \rho v^2 A\ \ C_D$

Where, ρ= density

ν= velocity of air
A= area of the model
C_L= co-efficient of lift
C_D=coefficient of drag

Table 2. Theoretical lift and drag

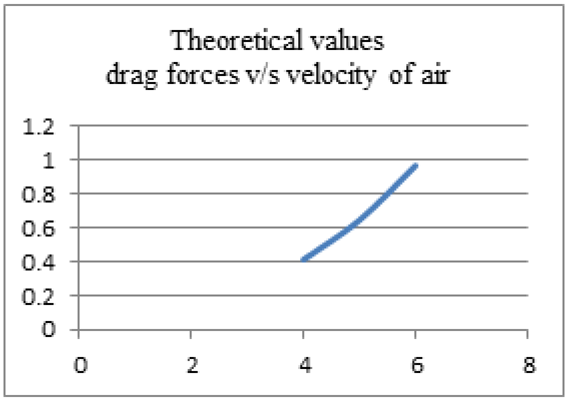
Velocity of air (m/s)	Drag force (N)
4	0.414
5	0.648
6	0.97

Velocity of air (m/s)	Lift force (N)
4	0.689
5	1.076
6	1.923

Table 3. Experimental lift and drag

Velocity of air (m/s)	Drag force(N)
4	0.39
5	0.65
6	1.04

Velocity of air (m/s)	Lift force (N)
4	0.712
5	1.223
6	2.133



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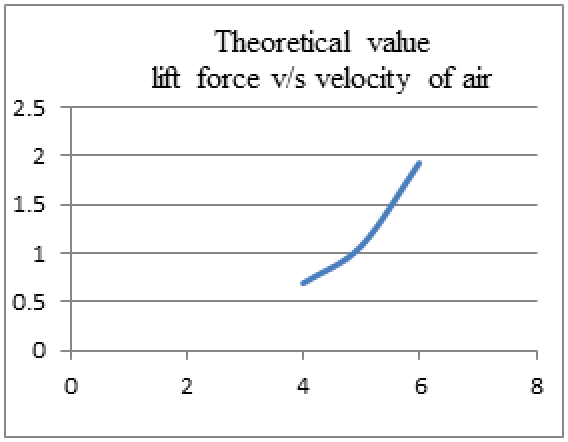

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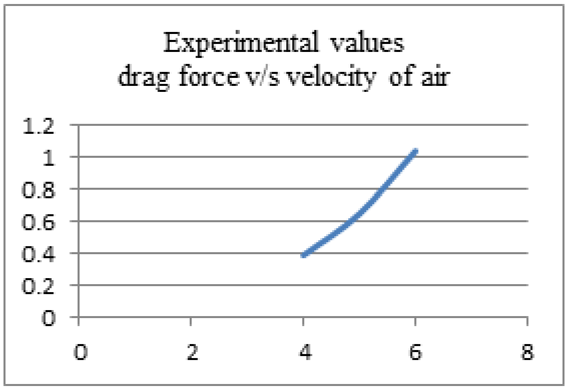

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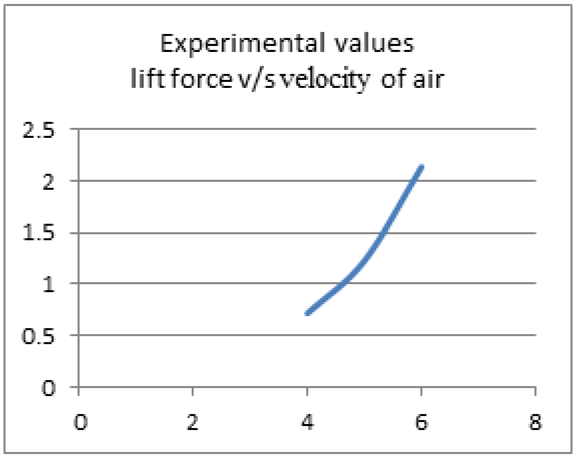

Figure 8.

V. CONCLUSION

Based on the results of the tests, this wind tunnel proved to be effective. It produced results that agree with accepted trends and this established confidence that this wind tunnel can be used in future aerodynamic experiments.

The construction of an open type blower wind tunnel is a very practical process; however, more time should be put into planning the best way to design different components of the tunnel, especially in regards to the contraction cone (or The Contraction Cone and the Test Chamber section were given special attention as they have direct influence on the scale model testing and the data generated) The design could lead to higher velocity in the test section, meaning a smaller fan can be used or less energy to achieve quality wind speeds and more laminar flow. Future research with this wind tunnel should include the development of a more sensitive measurement apparatus. If highly accurate results are desired and a sufficient budget is available, it would be beneficial to purchase a Multi-Axis Force/Torque Sensor [15, 16]. This device would offer the ability to measure all six components of force and torque. Having this capability would offer a much more comprehensive approach to gauging the effectiveness of this wind tunnel and would also offer opportunities for more significant experiments.

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