Design, Construction, and Setup of Low-Speed Open Circuit Wind Tunnel

Hari Sharan Dangi[1*], Dipendra Basnet[1], Roman Shrestha[1], Utsav Karki[1]
[1]Drone Development Unit, National Innovation Center, Kritipur
*sharanhari84@gmail.com

(Manuscript Received 29th August, 2024; Revised 22nd October, 2024; Accepted 26th October, 2024)

Abstract

The wind tunnel is an arrangement to simulate real aerodynamic parameters. An open circuit wind tunnel does not circulate the same fluid as working fluid rather uses environmental fluid circulated by a fan. This research paper documents the design, construction, and setup of a low-speed subsonic open wind tunnel at the National Innovation Center, Kirtipur. This wind tunnel produces a controlled stream of air to test the aerodynamic properties of objects or fluids. The wind tunnel developed at NIC is used for a variety of research activities related to the aerodynamics of different bodies such as testing of lift coefficient, drag coefficient, and pressure difference calculations on drones and rockets along with flow visualization in civil works signature bridges and high-rise buildings. Designed to be a general-purpose wind tunnel, it is the biggest of its kind in Nepal.

Keywords: Simulate, Aerodynamic, Subsonic, Lift, Drag, Flow visualization,

1. Introduction

The wind tunnel is a device to make airflow at the desired speed. The earliest wind tunnels were invented towards the end of the 19th century, in the early days of aeronautic research, when many attempted to develop successful heavier-than-air flying machines (Joglekar & Mourya, 2014). There are two main types of wind tunnel: closed circuit and open circuit. For the open circuit type, the test section is either closed or open (Nguyen, 2014). An open wind tunnel is a type of wind tunnel that uses a fan to create a stream of air that flows over a model. The model is typically placed in the center of the wind tunnel (in the test section), and a series of adjustable vanes control the airflow. Open wind tunnels are used to study the aerodynamics of objects, such as cars, airplanes, and buildings. They are also used to test the performance of parachutes and other flying objects.

Open wind tunnels are relatively simple to construct and operate, which makes them a popular choice for small-scale experiments. Although an open circuit occupies more space than a closed-circuit wind tunnel, it requires a relatively low budget to fabricate. At the same time, it is superior for propulsion and flow visualization as there is no accumulation of exhaust products.

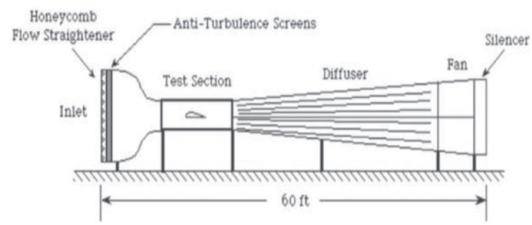

Figure :1 UIUC low-speed open-end wind tunnel schematic diagram
(Ref: www.learnpick.in/prime/documents/ppt/486/wind-tunnel)

1.1 Objective

To develop a multi-purpose low-speed wind tunnel that could be utilized for these purposes:

a. Lift coefficient and drag coefficient calculations of drone models.
b. Wind flow visualization over wings and fuselage.

c. Force calculations of the rocket model
d. Flow visualization over the architectural or urban landscape.
e. Drag calculation and visualization of new vehicle models.

2. Materials and Methods

2.1 Design Methodology

The design of a wind tunnel starts with the purpose of development of the wind tunnel and the size of the testing bodies. The dimensions of the test chamber have a greater impact on the wind tunnel's overall dimensions. The bigger the test section, the bigger the wind tunnel dimensions. Along with this, the budget and space available also play a key role in influencing the steps further down the line in its development. After the scope and resources have been identified, the process begins with defining some ground rules for the calculations ahead.

- Working fluid = ambient air
- Operating regime = subsonic
- Drive type = fan

The wind tunnel design and development rests on the mentioned parameters.

Table 1: Design Specifications

Drive System	Fan
Operating Fluid	Air
Duct Circuit	Open
Operational Flow Regime	Subsonic (M = 0.4)

Looking at the choices for the test section design, the nozzle(cone) is also designed to have maximum flow acceleration without any turbulence and flow separation. Then, after that Tunnel Fan is chosen and then the diffuser is designed to increase the pressure of fluid(air) gently out in the atmosphere, and at the end, the settling chamber with honeycombs and screens are subtly placed.

The wind tunnel will operate with ambient air in a subsonic region, producing a maximum flow velocity of 60 m/s in the test section. This value is required to match the conditions of the real world in the test model by scaling down.

Thereby, the wind tunnel will consist of a settling chamber (housing screens and honeycombs), a contraction nozzle, a test section, a diffuser, a drive section and an optional silencer after the drive section.

2.1.1 Test Section

Design phase starts with defining the dimensions of the test section of the wind tunnel.

For that, it begins with the shape of the wind tunnel test section. The circular cross-section is the best for wind tunnels. However, when thought practically, the square cross section is suitable, and hence is chosen in our case as well.

With that sorted, it is needed to determine the dimensions of the square cross-section of the test section. Based on test subjects, it was concluded that a test section of the square cross-section with 600mm side length is optimum for our case.

To obtain the test section length, the hydraulic diameter (also known as, characteristic length) is calculated. For a square cross-section, the hydraulic diameter is given by:

$$D_s = 2\sqrt{\frac{\Omega_{ts}}{\pi}} \tag{1}$$

Where,

Ω_{ts} = cross sectional area of the test section (0.36 sq.m.)

When l_{ts} = 0.5 is required for the flow to be uniform and if $l_{ts} > 3$, it could lead to increased boundary layer thickness.

Preferably, .

Thus, the obtained length of the test section would be 1218mm, giving the final dimension of the wind tunnel test section as 1200mm.

we aim to place on the test section should be less than 0.8 of the tunnel width. They call it “Rule of Thumb”. Means, if we are putting a wingspan of 320ft on it, then the required test section should be 400 ft wide at least.

2.1.2 Contraction Nozzle

The contraction section is required to concentrate the flow to obtain the required flow velocity at reduced turbulence.

The first defining parameter of the contraction section is its nozzle area ratio. It should be as large as possible since it ensures max flow acceleration and low total pressure losses in upstream sections (Kareem, Abbas, & Khammas, 2021).

Usually, it should be within 6 to 10. If it is less than 6, it causes high-pressure losses in upstream wind tunnel components, such as screens and honeycombs. On the other hand, if it is higher than 10, it results in excessive cross-sectional dimensions of the inlet.

For our case, a nozzle area ratio of 9 was used as it falls within the limit and holds the merit of the continuity equation for a streamlined flow, (i.e. $A_1 x V_1 = A_2 x V_2$) to our side, which means higher the ratio of the nozzle area, higher could be the achievable flow velocity at the test section.

The second defining parameter is its length. It is given by:

L = k x H

Where, H = inlet height (1800 mm)

k = a constant such that $0.667<k<1.79$

If $k<0.667$, there will be detachment before the outlet of the nozzle. And, if $k > 1.79$, it results in an increased boundary layer thickness. So, we took k=1.0556 as a good trade off.

L = 1900 mm

The third defining parameter of the contraction section is its longitudinal section profile. As noted by Siregar and Umurani Siregar & Umurani, 2019) the wall contour shape of the nozzle was taken as a fifth-order polynomial, which was also supported by Mehta & Bradshaw (Mehta & Bradshaw, 1979).

2.1.3 Diffuser

The diffuser decelerates the high-speed flow from the test section, thereby achieving static pressure recovery and reducing the load of the drive system.

As in the case of the contraction section, the defining parameter for the diffuser section is its area ratio.

The area ratio is given by:

$$AR = \Omega_{ds}/\Omega_{ts}$$

$$\text{And, } 2 \leq AR \leq 3 \qquad (2)$$

If AR>3, there will be irregular flow velocity at the fan inlet. And AR<2, if , there will be an increase in overall wind tunnel dimensions. Thus, smaller AR is desirable.

Another important parameter in diffuser design is its cone expansion angle. Its value should be between 2° and 3.5°, with a smaller angle being more desirable (Boyle & Knaub, 1988).

Care must be taken in selecting the expansion angle and AR, since the overall length of the diffuser should be 3 to 4 times the length of the test section.

For our case AR ratio of 2.5 was chosen, giving the outlet fan area as 0.9 m^2. Similrly, the diffuser angle was taken as 3°, making the total length of the diffuser to be 4500 mm.

2.1.4 Drive Section

The diameter of the drive section is given by:

$$D_{ds} = 2\sqrt{\frac{AR \times \Omega_{ts}}{\pi}} \qquad (3)$$

AR = 2.5

Ω_{ts}= 0.36 sq m

D_{ds} = 1070.49mm (107mm taken)

The drive section selected is an axial fan that resides at the bigger end of the diffuser section of the wind tunnel. The axial fan is a type of fan that uses a series of blades to move air in a straight line. The fan is powered by an electric motor, which causes the blades to rotate. As the blades rotate, they create a stream of air that flows through the wind tunnel. The air is then accelerated by the diffuser section, which is a cone-shaped chamber that helps to reduce the speed of the air and increase its pressure. The accelerated air then flows through the test section of the wind tunnel, where it can be used to test the aerodynamics of various objects.

The axial fan is a good choice for the drive section of the wind tunnel because it is efficient and has a high flow rate. Regarding the noise level of the axial fan, no acoustic investigations were carried out and if the level is too high, we plan to attach a silencer section at the end of the drive section.

2.1.5 Settling Chamber

Among the different shapes of honeycomb cells, hexagonal is preferred over circular and square ones as it has the lowest pressure drop coefficient. But, in our case due to easy availability of polycarbonate sheets which have square cross-sectional holes, we have opted for this instead of hexagon type. However, we might use arrays of 1-inch pipes for it being a viable and economic option.

2.1.6 Instrumentation

Due to the time constraints and low feasibility regarding cost as well as local manufacturing capabilities, the instrumentation and data acquisition system for the wind tunnel could not be manufactured locally. As a result, potential vendors were called on to obtain quotes for the components of interest. Nepali vendor Mantra Inc. was requested and responsible for the procurement of the mentioned first three required instrumentations from India.

Some of the instruments are given as follows.

a. 6 component forces balance with digital 6 component indicators
b. Pitot tube anemometer and differential
c. Heavy duty industrial axial flow fan
d. Electric smoke generator

2.2 Prototype Development

Prior to the construction of the actual wind tunnel, initial flow analysis and simulations were run and after the result showed test section velocity nearly equal to 60 m/s, a scaled model of the wind tunnel was developed to guarantee streamlined flow in the test section. This was done to avoid any potential problems with the airflow in the full-scale tunnel, which could have resulted in inaccurate results. The scaled model allowed us to test the design of the tunnel and make any necessary adjustments before building the final product. This ensured that the wind tunnel would be able to provide accurate results when used for testing.

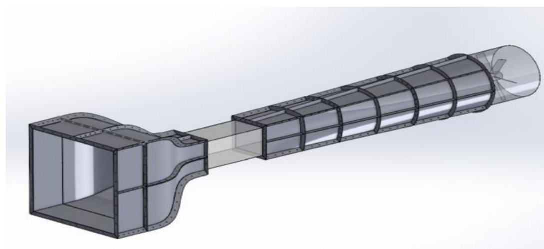

Figure 6: Wind Tunnel Design with Ribs for Support and Shape.

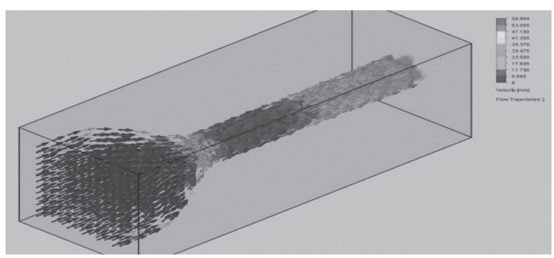

Figure 7: Flow Simulation in Solid Works Simulations

The prototype was constructed using PLA filament in a 3D printer. The prototype was scaled down to 0.0056 times the actual designed body. The external structure of PLA with acrylic sheet honeycomb and test sections, a centrifugal blower type fan (CBM-970533B-168) was used for the drive section. Finally, a small model of Clark-y airfoil was designed and tested for flow visualization with the smoke.

Figure 8: Prototype of Wind Tunnel

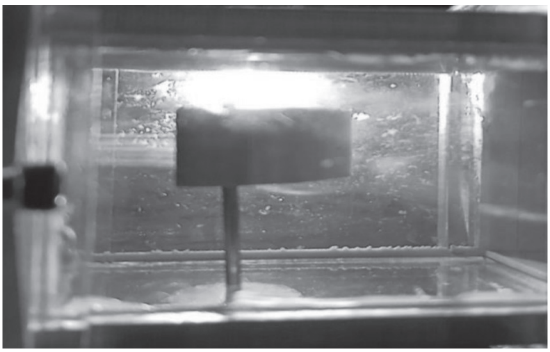

Figure 9: Flow Visualization

2.3 Setup

After the good flow visualization in the prototype, the wind tunnel body was ready to be fabricated. Each section is divided into 4 parts for easy fabrication of all those humongous body sections. The parts like the settling chamber, contraction cone, and diffuser have been fabricated and made ready for assembly purposes. And, with the arrival of the drive section and other instruments the stands and test sections would be fabricated in a supposed lesser time.

The wind tunnel is to be constructed in a large, open space at NIC. So, a different building of 15 by 6 m in length and width is also being made to incorporate the wind turbine.

The walls of the wind tunnel are made of 1.8 mm steel sheets. The ribs of MS with thicknesses 3 and 5 mm are used for structural support. The test section is considered to be fabricated using acrylic sheets of 5-10 mm thickness to facilitate easy visuals of the flow phenomena in the test section. The test section has to incorporate different instruments like force balance, anemometer, and multitube manometer so its fabrication has been postponed till the arrival of the instruments. Square or rectangular bars are supposed to be used as stands of the structures.

2.4 Calibration of Equipment

We employed several calibration techniques during wind tunnel setup and testing. Here are common calibration techniques that we have used.

a. Pitot Tube Calibration
b. Anemometer Calibration
c. Force Balance Calibration

3. Testing and Results

The experimental setup for testing was meticulously optimized for repeatable conditions. The subsonic open-circuit wind tunnel, featuring a 1.2m × 0.6m × 0.6m test section, facilitated airflow veslocities of up to 50m/s. A honeycomb inlet structure minimized turbulence, ensuring uniform airflow over the model. At the outlet, a powerful fan maintained steady airflow, preventing stagnation. This design fostered controlled conditions essential for accuracy. aerodynamic testing, guaranteeing reliable and consistent experimental results.

The connecting stand was utilized to securely mount the wing section in the test section of the tunnel. The stand was positioned to provide good stability for the model during operation. The stand is related to the load cell which transfers data to the digital data acquisition system. Proper connections were established between the velocity control system and data acquisition. Devices and sensors ensure no signal interference or data loss. The wind tunnel velocity control system was calibrated and adjusted to achieve the desired airflow velocities, which involved fine-tuning the fan speed and measuring the velocity in the test section using a pilot tube anemometer and manometer.

Table 2: Theoretical Result calculated in ANSYS

Angle of Attack	Velocity	20m/s	25m/s	15m/s
0	Lift Coefficient	0.766	1.2044	0.428
	Drag Coefficient	0.14	0.213	0.0828
12	Lift Coefficient	2.9	4.558	1.62
	Drag Coefficient	0.566	0.88	0.23

Table 3: Experimental Result from Wind Tunnel

Angle of Attack	Velocity	20m/s	25m/s	15m/s
0	Lift Coefficient	0.7	1.3	0.5
	Drag Coefficient	1.6	2	1.3
12	Lift Coefficient	3	4.7	1.7
	Drag Coefficient	1.9	2.4	1.3

4. Conclusion and Recommendations

Fabrication of the low-speed subsonic wind tunnel has gone smoothly and has been completed successfully. After the successful completion of assembly, the performance evaluation of the wind tunnel in terms of achieving the desired airflow characteristics and speeds is done along with calibration and validation of the measurement instruments and data acquisition system.

Based on the project, it is recommended that the following be done:

a. The wind tunnel should be used for a variety of research projects. Collaborations with academic institutions or industry partners could expand further reach and usage of the wind tunnel.
b. The data collected from the wind tunnel should be used to improve the understanding of aerodynamics, fluid dynamics, and heat transfer.
c. The wind tunnel should be maintained regularly after completion to ensure its continued operation and reliability of its performance.
d. The possibility of incorporating additional features could be explored to simulate more complex real-world conditions.

References

Joglekar, B., & Mourya, R. M. (2014). Design, construction and testing open circuit low speed wind tunnel. International Journal of Engineering Research and Review, 2(4), 1–9.

Nguyen, Q. Y. (2014). Designing, constructing, and testing a low-speed open-jet wind tunnel. Journal of Engineering Research and Applications, 4(1), 243–246. Retrieved from www.ijera.com

Kareem, A. A., Abbas, M. K., & Khammas, F. A. (2021). Aerodynamic study of low-speed wind tunnel contraction section: Design and manufacturing. IOP Conference Series: Materials Science and Engineering, 1094(1), 012077. https://doi.org/10.1088/1757-899X/1094/1/012077

Siregar, R. A., & Umurani, K. (2019). Laboratory development of low speed wind tunnel for educational purposes. IOP Conference Series: Materials Science and Engineering, 670(1), 012059. https://doi.org/10.1088/1757-899X/670/1/012059

Mehta, R. D., & Bradshaw, P. (1979). Design rules for small low speed wind tunnels. The Aeronautical Journal, 83(827), 443–449. https://doi.org/10.1017/S0001924000031985

Boyle, M. T., & Knaub, C. (1988). Low speed wind tunnel testing. https://doi.org/10.1109/SEMTHE.1988.10594