Aerodynamics in Practicality - Abdullah Salman.pdf

by Mr Adnan

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Aerodynamics in Practicality

Abstract

Energy efficiency is an element physicists and engineers continuously strive for, one factor for most energy losses is poor aerodynamic design in systems where fluids such as air are involved. With this research we aim to explore some techniques of maximizing lift forces to whilst maintaining efficiency.

A wind tunnel was built to conduct the tests with a load cell setup that would allow to take readings up to the nearest two decimal places, measured in grams. Due to physical limitations, all tests were conducted at exactly the same fan velocity and a mathematical relationship was applied to plot graphs at various speeds.

Tests were conducted concerning two types of airfoils, the standard airfoil and the stepped airfoil to see which design provides the most magnitude of Lift. An airfoil was 3D printed and tested with some positive camber. The initial test was conducted at a fixed angle of attack of forty five degrees. For the second test, a servo motor (to which the airfoils were attached to) was used to vary the angle of the airfoil relative to the upstream airflow direction from negative twenty to forty five degrees.

The standard airfoil produced more Lift than the stepped airfoil as a result of the first test, perhaps due to less drag forces acting upon it. For the second test, Lift values at different angles were compared and it turned out that the stepped airfoil had a more robust Lift value relative to the standard airfoil, especially at lower angles of attack.

Some assumptions should be taken into account when drawing conclusions, assuming that the boundary layer effects remain uniform at higher velocities and any suction forces (due to the Pressure gradient) in the test chamber relative to the apparatus were ignored. Hence only comparative analysis can be conducted from these tests as some values may be inflated due to the aforementioned suction forces.

Some parts such as the flow straightening meshes and the airfoil were designed in FreeCAD and 3D printed.

Terminologies:

Boundary Layer: The first layer of a fluid that is in contact with the surface.

Skin Drag: Drag that acts tangential to the external surface of a body due to fluid flow.

Eddies: The swirling of airflow when it enters a turbulent pattern.

Angle of attack: The angle of a test subject, usually flat plates/airfoils relative to the flow direction.

Camber: The asymmetrical nature of an airfoil about it’s centerline

Reynolds Number: A coefficient which indicates how laminar or turbulent a fluid flow is.

Research Paper

Apparatus:

- Anemometer:

A device used to measure the speed of airflow

- Load Cell:

A sensor which is used to measure a force. The sensor was derived from an existing weighing scale with a relatively high accuracy, the scale was modified as per the requirements of the tunnel. The data provided by the load cell will provide insight on the magnitude of force being exerted on the test subject.

- Wind Tunnel:

Wind Tunnel Technical Specifications:

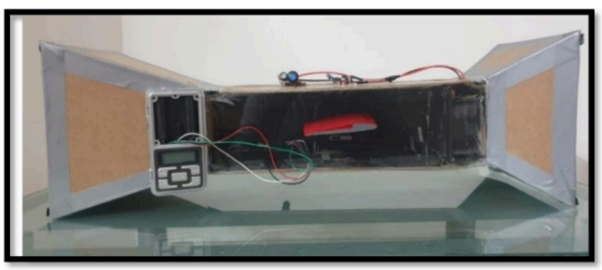
Fan configuration: Blow down Propulsion

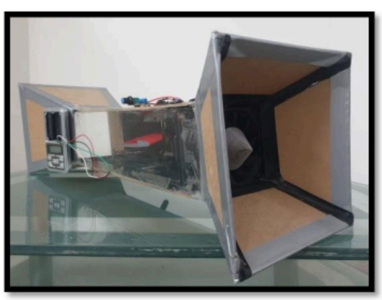
Mach Number = 0.03

Contraction Ratio = 2 : 1

Max Wind Speed = 9.0 m/s²

Hydraulic Diameter = 0.099 m





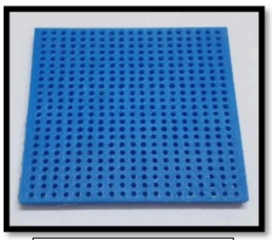
Configuration details:

A blow-down propulsion fan configuration was used in which the fan is placed upstream of the test subject. This configuration allows for a higher speed and is easier to operate. In these tests we will use a load cell that will measure the change in mass of each test subject. The change is mass is then converted to the corresponding Lift Force reading.

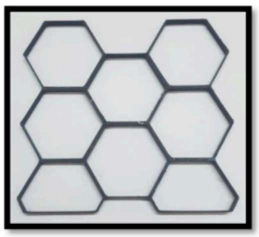
Wind Tunnel Parts:

- Flow Straightening Mesh

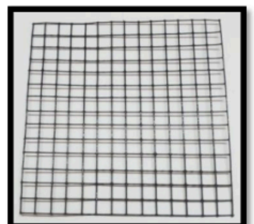
A mesh was designed and 3D printed with the aim of straightening any turbulent airflow when entering the wind tunnel test section for ideal results. This design however has low porosity and reflects away most of the incoming air. Therefore a new mesh was designed and printed, this time with much higher porosity. To further reduce the vortices formed by the fan, another mesh is used, this metallic mesh is placed upstream of the hexagonal mesh, after the fan



Low Porosity Mesh



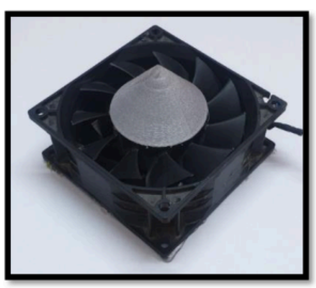
High Porosity Mesh



Primary Mesh

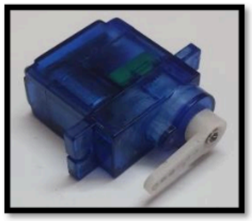
- Flow Generating Device

A 12V CPU fan was used to draw air into the test section by placing it in the contraction zone. To further improve the fan efficiency, a 3D printed cone was also fixed onto its center



- Servo

An SG90 positional servo was used to control the angle at which the airfoils were tested.



- Load Sensor System

The load cell sensor had a maximum reading capacity of 200 grams, the wires were extended to be suitable to operate

<u>Airfoil types</u>:

Standard airfoil

Stepped airfoil

The airfoils were designed in FreeCAD and the design was slightly cambered to generate higher lift values at lower velocities. The airfoils were covered in tape to reduce skin drag. It should be noted that both airfoil are the same but with modifications

Airfoil Reynolds Number = 29400

<u>The difference between standard v/s stepped airfoils</u>:

Stepped airfoils have a section of body work removed approximately twenty five percent of the airfoil down the leading edge. Due to their aggressive design, they can delay the stalling point by generating vortices allowing for more Lift Force to be produced at higher angles, although too much angles can be harmful due to their preexisting turbulent nature.

Methodology

Test 1: Lift Force comparison values between Stepped v/s Standard Airfoils

A positively cambered airfoil was 3D printed and tested. This test was conducted with the airfoils at a fixed angle of attack of forty five degrees. The change in mass observed from the sensor display was converted to Lift Force via the relation

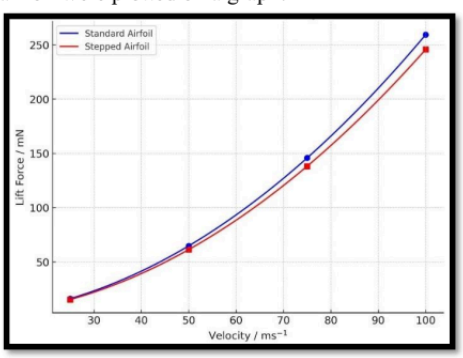
1 Newton = 9800 grams

Due to physical limitations, higher speeds cannot be simulated in our wind tunnel. Hence can use the relationship between the Lift Force and Velocity to calculate the Lift Force values at higher Velocities by the formula:

$F_L = \frac{1}{2}\rho A v^2 C_L$ (where: **F_L → Lift Force {N}, ρ → Fluid Density {kg/m³}, A → Object Surface Area {m²}, V → Wind Velocity {m/s}, C_L → Lift Coefficient)**

By treating $\frac{1}{2}\rho A C_L$ as a constant, we can develop a relationship where the Lift Force is proportional to the square of velocity. Hence: **$(F_{L1}/v^2_1) = (F_{L2}/v^2_2)$**

The test results of each airfoil were plotted on a graph.

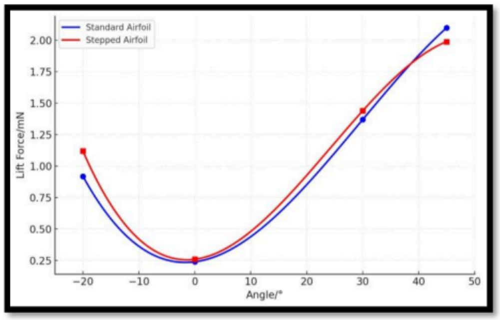


It can be concluded from the test that standard airfoils tend to generate more Lift Force relative to stepped airfoils, especially at higher air flow velocities. This result can be matched with the fact that stepped airfoils tend to create a vortex that causes high amounts of Drag and also affects the Lift generation in the process.

Test 2: Lift Force comparison b/w Standard v/s Stepped Airfoils at different Angles Of Attack (AOA)

The same airfoils were now connected to a servo and their angles of attack relative to the flow direction were varied from zero to forty five degrees, then the airfoils were set in a reverse angle of attack with angle twenty degrees to note the comparison in Lift Force values between both the airfoils.

The test results of each airfoil were plotted on a graph.



It can be concluded from this test that the stepped airfoil is able to generate higher values of Lift Force relative to the standard airfoil, this is more prominent in lower angles of attack. The stepped airfoil is also able to outperform the standard airfoil at reverse angles of attack as well with the standard airfoil only managing to best the stepped variant at higher speeds.

Perhaps the result can be matched with the fact that the vortex generation from the discontinuity of the stepped airfoil would energise the boundary layer delaying the stalling point until a certain extent.

Research Limitations and suggested improvements

- A fan with a higher CFM value could be used which would allow more air to be propelled through the test section allowing more flexibility.
- The blowdown fan configuration though effective does come with a drawback generating vortices.
- A boundary layer remover could also be used to remove any detached airflow.
- The boundary layer is assumed to remain uniform at higher velocities which may not necessarily be the case at all times.
- The wind tunnel contraction ratio can be increased to allow for much higher velocity tests (due to the Venturi principle) to be conducted which would bring more accuracy to the tests

Due to the sensitive nature of the load cell and vibrations from the fan, the load cell was projecting many values constantly and not settling to a particular value, hence a range of values was noted and averaged.

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