Engineering Studies

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Aeronautical Engineering

Testing for lift

This unit of work addresses aspects related to the following syllabus outcomes:

> **H2.2:** Analyses and synthesises engineering applications in specific fields and reports on the importance of these to society.
>
> **H6.2:** Demonstrates skills in analysis, synthesis and experimentation related to engineering.

Source: Board of Studies (1999) *Stage 6 syllabus, engineering studies, preliminary and HSC courses*. Board of Studies: Sydney

The Wind tunnel

Wind tunnels have been used for many years as a means of studying the behaviour of shapes exposed to low, and high, speed airflow. The most logical application of the wind tunnel is for improving aircraft performance, but wind tunnels are widely used to study efficient aerodynamic shapes for motor vehicles, road transports and high-speed trains. They are also used to study the effects of high-rise buildings on the natural airflow of a city landscape.

Wind tunnels have been built to study aircraft shapes in both **sub-sonic** and **super-sonic** airflow.

The basic principle of a wind tunnel is to produce a uniform flow of air in a chamber of a size suitable for a model to be placed in. This is achieved by the use of an artificial means of producing an airflow (wind) using a fan, an area within the tunnel designed to even out the flow, a test zone where models can be mounted, and an exhaust zone. Most modern wind tunnels recirculate the airflow by feeding the exhaust back to the fan stage.

Simple, low speed, wind tunnels use **manometers** placed on the model to measure changes in air pressure over the surface of the model. Telltale streamers on the surface of the model can also be used to indicate linear and **turbulent** flow. Modern sophisticated wind tunnels use complex computerised systems to measure pressure changes, air velocity and the forces generated.

It is possible to build a simple model as follows:

Wind tunnel materials

Collect three clean cardboard boxes of the same size (approx. 307 x 208 x 208 mm), with top and bottom flaps still intact. The ones used for this experiment were wine bottle boxes with internal cardboard bottle separators. These are shown in the photograph below.

You will also need a

- Rule, pencil, scissors, masking tape, paper knife.
- Domestic fan, approximately 355 mm diameter, single or multi-speed.
- Electronic scale, Sartorius (500g max). (Try the school science department.)
- Optional: Wind speed indicator, Davis Instruments, Turbometer.

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Wind tunnel construction

The most difficult task in the construction was to create the transition piece between the circular fan safety screen and the rectangular tunnel shroud. Students should be able to do this, as it is a part of the requirements for Engineering Studies Civil Structures (syllabus, p. 32).

The flaps of the lid were used as a starting point, and triangulated to form the transition shape. They were then taped together to form a sealed interface between the fan and the rectangular shroud.

The next task is to provide a means of making the airflow as uniform as possible. Tape a small length (70 mm) of tissue strip (1.5 mm wide) on the end of a skewer and hold the strip in the airstream just in front of the fan. You will soon find that the airstream flows in different directions in different places. This is caused by the inefficient blade shape and the blade rotation. To improve the flow, a network of rectangular *tubes* can be made from the cardboard bottle separators that came in the boxes. In this model these were about 80 mm square, but it is suggested that 50 mm square would be better. These were inserted into the shroud and fixed flush with the original bottom of the box.

A test of the airflow at this stage showed some dead air spots on the sides and bottom of the airstream, and so these passages were blocked off at the end away from the fan itself.

The bottom flaps for the first box and the top flaps of the second box were then folded outwards. These were taped together and an extension added to one flap to produce a support which holds the tunnel shroud in line with the fan axis. The extension used was 50 mm.

The bottom flaps of the second box were lined up with the sides of the box to extend the tunnel shape to 700 mm. A slot was cut in the bottom flap (30 x 150 mm) to allow the test mounting stand to sit in the airstream about 100 mm from the end of the tunnel shroud.

Test stand

The test stand is made from two parts, the base and the upright. The base is a piece of MDF 125 sq x 12 mm with a 12 mm hole in its centre. The upright is a piece of 12 mm dowel, 250 mm long. This is glued into the base, and slotted at the top to take the protractor shaped addition on the wing section.

Construction time

This simple wind tunnel was built in two and one half hours.

The model wing, and its stand were constructed in about six hours.

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Setting up

The general set-up can be seen in the photographs. The transition piece is taped to the fan safety screen to stop it falling off. The tunnel axis must be in line with the fan axis. The test wing should be in the centre of the airflow (on the axis of the fan). It can be adjusted in height with suitable spacers under the base of the test stand.

Before testing any wing sections, check that the airflow at the shroud exit is reasonably straight and even. To do this use a tissue streamer taped to a skewer, and move it around in the airstream. Dead areas within the airstream will show up with the streamer hanging down limply.

If you have access to a wind speed indicator you can use this to determine the uniformity of airflow. Turn the indicator on and place it in the exhaust airflow without obstructing or deflecting any of the exhaust, i.e. don't stand in front of the exhaust such that a back pressure will be set up to cause false readings (stand well to the side). Take readings from a number of places in the airstream after waiting for the Turbometer to stabilise its reading.

The fan used in this experiment was a three speed version. Nine readings were taken with a wind speed indicator, at each of the fan speeds. The following table summarises the results.

Fan speed	Lowest airflow	Highest airflow	Average airflow

Low	1.0 m/s	2.2 m/s	1.6 m/s
Medium	1.3 m/s	2.7 m/s	1.9 m/s
High	1.5 m/s	3.0 m/s	2.2 m/s

It is interesting to note, but not unexpected, that the highest figure for each speed was in the top middle section, and the lowest speed in the bottom middle section of the shroud. The variation in speed across the section where the test wing is placed is not too bad for a simple model wind tunnel such as this. It could be improved by making the rectangular sections about 50 mm square rather than 80 mm square.

Test wing

The test wing used in this experiment was a 310 mm portion of the wing from a model glider. The commercial glider kit (*Flight Path Condor*) was designed and made in Australia featuring laser cut parts and all accessories (except glue), with a wing span of 870 mm. The wing section was constructed as per the kit instructions, but portion of the spars and only seven ribs were used. The tail can also be made up and tested in the wind tunnel.

A piece of balsa sheet was cut to a semicircular (protractor) shape and glued to the underside centre of the wing section to mount the wing to the test stand. A pivot hole was drilled and a scale in 5 degree increments was added from –10 to +30 degrees of angle. Zero degrees was equal to the bottom of the wing section being horizontal.

Any commercial model wing could be adapted to fit the tunnel, and you can design your own as well.

A fundamental question that could be tested is whether, or not, a flat sheet of balsa creates lift. Another test could try the effects of different cross sectional shapes of wing; **symmetrical** or **asymmetrical**, and different aerofoil thicknesses.

thickness ratio (t) = 100 x **thickness/chord**

The aerofoil thickness ratio of the model test wing used (12 mm thick and 109 mm wide) is,

t = 100 x 12 ÷ 109 = 11%

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Angle of attack

One of the prime factors that determines the amount of lift and drag produced by an airfoil is the angle of attack. The angle of attack is the angle measured between the direction of the airflow (the **free stream**) and the **chord line** of the wing cross section. The chord line in a simple airfoil can be considered to be the line drawn between the leading edge of the airfoil and its trailing edge. A symmetrical airfoil is the same shape on each side of the chord line, whereas an asymmetrical airfoil is not. In modern aircraft the airfoil thickness and shape (cross-section) changes between the fuselage and the wingtip. In the wing section used here the chord line is 3 degrees off the rather flat bottom of the airfoil. So, with the bottom of the airfoil horizontal the angle of attack is 3 degrees. The test stand allows the angle of attack to be varied from minus 12 degrees to plus 23 degrees

A wind tunnel test

To carry out a test, first place the wing and stand on the scales. The scales are then turned on and zeroed. Turn the fan on and allow it to run for 10 minutes, or so, to warm up and run at a constant speed. Adjust the wing to a given angle of attack, place it and the stand onto the scales facing the airflow. The reading on the scales will change. Allow a minute for the wing to stabilise in the airflow and then record the upward (lift) force, or downward force as changes in the mass reading on the scales. Take a series of readings for different angles of attack, and at different fan speeds. Make sure that the wing and stand are placed in the same location in the wind tunnel each time, and that the wingtips do not touch the sides.

Results:

The following table shows the results of tests done at the three fan speeds. The lift is measured in mass units (grams). The force equivalent of these measurements will be 0.0098 times the mass value in Newtons.

of Attack	Airspeed 1.3 m/s	Airspeed 1.7 m/s	Airspeed 1.8 m/s
-12	+4.2	+6.2	+7.6
-7	+1.8	+ 2.6	+3.3
-2	-0.3	-0.5	-0.5
+3	-2.6	-4.8	-5.0
+8	-4.6	-7.5	-9.0
+13	-6.7	-10.0	-11.8
+18	-8.4	-12.1	-14.4
+23	-8.7	-13.2	-15.8

In the range –2 to +13 degrees angle of attack this wing approximated the statement that lift varies to the square of airspeed:

$$L = (S/s)^2 \times l$$

where S & s are wind velocities (m/s)
and L & l = lifts (N)

Now try some other wing section shapes and *thickness ratios*.

Draw a graph of **angle of attack** to **lift.** Place the angle of attack along the X axis with the lift force on the vertical axis. When complete, answer the following:

At what angle of attack is lift zero?

The lift curves are relatively linear up to a particular angle of attack, but then lift drops off with further increase in the angle.

In this experiment this occurred at about +10 degrees.

What happens to cause this reduction of lift?

Aerodynamic forces

A good description of the aerodynamic forces set up on an aerofoil can be found by studying the site at:

http://www.wikipedia.org/wiki/Airfoil

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Revision Questions

Can you answer the following questions from this site?

1. **What is the point of impact?**
2. **What causes the upward force on the lower surface of an airfoil?**
3. **What principle leads to the low pressure area on top of the airfoil?**
4. **What are the components of the *total aerodynamic force*?**
5. **What three factors affect the amount of lift set up on a given airfoil section?**
6. **What happens as the angle of attack increases?**
7. **The wing section tested weighed 10.8g. What are the minimum conditions for it to fly?**

Answers

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Resources:

Copeland, P. (2001) *Engineering studies – the definitive guide. vol 2*. Anno Domini 2000: Allawah. pp168 – 174

Other Websites relating to the Aeronautical Engineering module:

http://www.corrosion-doctors.org

For information about building a model wind tunnel, try these links:

http://www.faa.gov/education/educator_resources/educators_corner/grades_9_12/wind_tunnel/

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