Experiment F1

FORCES ON VARIOUS BODIES IN AN AIRSTREAM

1 – INTRODUCTION

The report details the theory and experimental method of how to determine the forces on different bodies within an air stream. The theory involves the drag and lift coefficients. The first experiment will measure the drag force on a sphere and how it varies. This is then repeated for different axisymmetric bodies. The last experiment will measure how the lift and drag forces on an aerofoil vary with angle of incidence.

1.1 Purpose of Experiment

- To observe quantitatively how the drag force varies on a sphere with the velocity of the airstream.
- To measure the drag forces of various axisymmetric bodies (all with the same circular maximum cross section and axis of symmetry aligned in the flow direction) and to observe how the forebody and afterbody shape affect the drag.
- To observe how lift and drag forces on an aerofoil vary with angle to the airstream.
- Explain the nature of force variation and local flow direction at various points around a body using a wool-tuft for investigation.

1.2 Background and Theory

Relative motion between a body and a fluid (when a body moves through a fluid at rest or when a fluid flows over a body) causes a force on the body. The horizontal component of this force is the drag and the vertical component is the lift.

The magnitude of these forces depends on numerous factors. Those to do with the body; the shape, attitude, size and in some cases the surface roughness. Those concerning the fluid; density, viscosity, unsteadiness and turbulence in the fluid stream. The velocity of the relative motion is also important (if high enough to approach the speed of sound in the fluid).

However, during this experiment surface roughness, unsteady and turbulent flow cannot be investigated and the velocities are low compared to the speed of sound in the fluid. Under these conditions the force felt at a particular attitude can be written as shown in equation 1, as a function of size of the body, the density and viscosity of the air and the velocity.

$$F = f\left(l, \rho, \mu, u\right) \qquad \text{(Equation 1)}$$

By using dimensional analysis, to make the equation homogenous with respect to the three independent dimensions (mass, length and time). The relationship shown in equation 2 can be discovered.

$$\frac{F}{\rho u^2 l^2} = f\left(\frac{\rho u l}{\mu}\right) \qquad \text{(Equation 2)}$$

By convention, the length squared term is interpreted as an area and factor of a half is introduced into the force term, giving equation 3:

$$\frac{F}{\frac{1}{2}\rho u^2 .area} = f\left(\frac{\rho u l}{\mu}\right) \qquad \text{(Equation 3)}$$

Now, the $\frac{F}{1/2\rho u^2 .area}$ term can be defined as a force coefficient (C_F) and the $\left(\frac{\rho u l}{\mu}\right)$ term defined as the Reynold's number (Re). The components of the force can now be expressed as coefficients:

Coefficient of drag = $C_D = \frac{drag}{\frac{1}{2}\rho u^2 .area}$ (Equation 4)

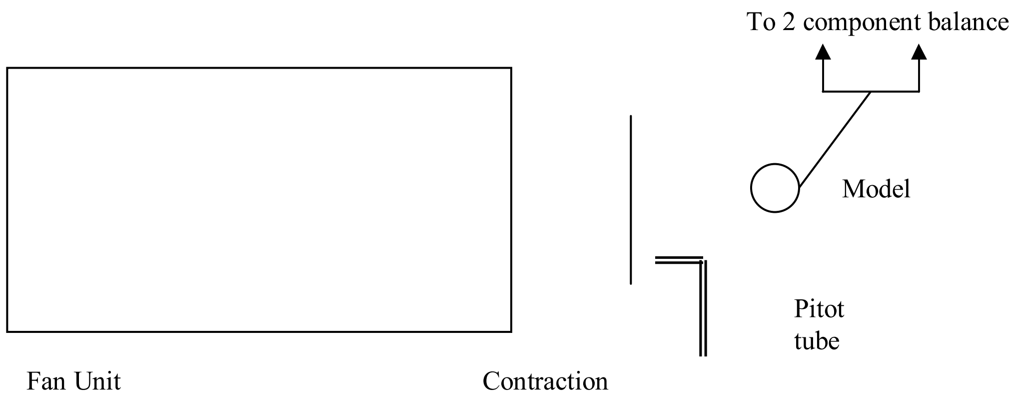
Coefficient of lift = $C_L = \frac{lift}{\frac{1}{2}\rho u^2 .area}$ (Equation 5)

For object which are not prismatic in cross section, the area is taken as the frontal area. In the case of spheres the maximum cross sectional area is used and the length term used in the Reynold's number is taken as the diameter. For lifting bodies, the area used is the plan area at zero incidence and the length used is the chord length.

The force coefficients are a function of Reynold's number. However for certain ranges of Reynold's number the force coefficients are almost independent of Reynold's number. If this is the case, the coefficient can be considered to be constant and so the force is directly proportional to the velocity squared, the density of fluid and the area. The force coefficient will, be different for different shape bodies and for different attitudes.

2– APPARATUS

2.1 Experimental setup



2.2 Experimental theory

An axial flow fan is connected to a motor, by changing its power input, the velocity of the airstream can be changed and measured using the pitot tube. The tube is positioned in the exit plane of the contraction and will measure the local pitot pressure. The flow coming out of the contraction can be assumed parallel so static pessure across the flow will not change and be equal to atmospheric pressure. Thus using Bernouilli's equation, the velocity can be calculated using the difference between pitot and ambient atmosphere pressure:

$$p_0 - p = \frac{1}{2}\rho u^2 \quad \text{(Equation 6)}$$

An inclined tube manometer was used to gain accurate measurements of pressure. The change in pressure and can be calculated by measuring the change in length of inclined fluid, *l*, and using the hydrostatic equation:

$$\Delta p = \rho_m g l . \sin \vartheta$$

Where ρ_m is the density of the manometer liquid
θ is the angle of the tube to the horizontal

The two component spring balance enables the force components in both horizontal and vertical directions independently of each other. The wool tuft is attached to a probe, so that the local direction of flow at any point can be investigated.

2.2 Experimental method

The manometer liquid level was set to zero and the inclination was adjusted until most suitable and the pitot tube connected to the manometer (the pitot tube was connected to the resevoir, the other end left open to the atmosphere).

The sphere was mounted on the component spring balance and paced roughly in the centre of the airstream parallel to the pitot tube. The initial readings of the component spring balance were recorded.

For a range of different speeds (controlled using the power of the motor) the manometer and drag readings were recorded. The wool tuft was used to observe the changes of flow around the body and determine the separation point and diameter of the separation region downstream of the body.

The same was repeated for other axi-symmetric bodies (replacing the sphere); the drag was measured at the maximum velocity and the separation region was estimated using the wool tuft.

Next, a symmetric aerofoil (mounted with zero angle of incidence to oncoming airflow) was positioned near to the centre of the airstream. At maximum airspeed the manometer reading was taken. The angle of incidence was increased by intervals of 5 degrees until 45 degrees. At each interval the manometer reading, drag and lift were recorded.

3 – RESULTS