Bernoulli: pressure reduction in turbulent flow

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The terms in Bernoulli's equation are energy densities due to pressure, and to kinetic and potential energy, in laminar flow for an incompressible fluid. The equation predicts a reduction in pressure due to tangential flow over a surface given by ...

$$\Delta P = {}^{1}/_{2}\rho v^2$$

… where ρ is the density of the fluid and v is the tangential velocity.

The relationship may hold approximately in a turbulent flow in air that is compressible, when turbulence and any changes in density are not the dominant factors. Pressure reduction in turbulent airflow can be studied with minimal equipment as follows.

A small slit has been cut in a 5 cm diameter polystyrene ball with a sharp knife and the ball has been mounted over the hook of a force probe. The hemispherical top section of a PET bottle is shown mounted firmly with double sided tape to cover the ball with a uniform surrounding gap of 5 mm. A wide bendy drinking straw has been inserted through a tight fitting hole in the bottle cap.

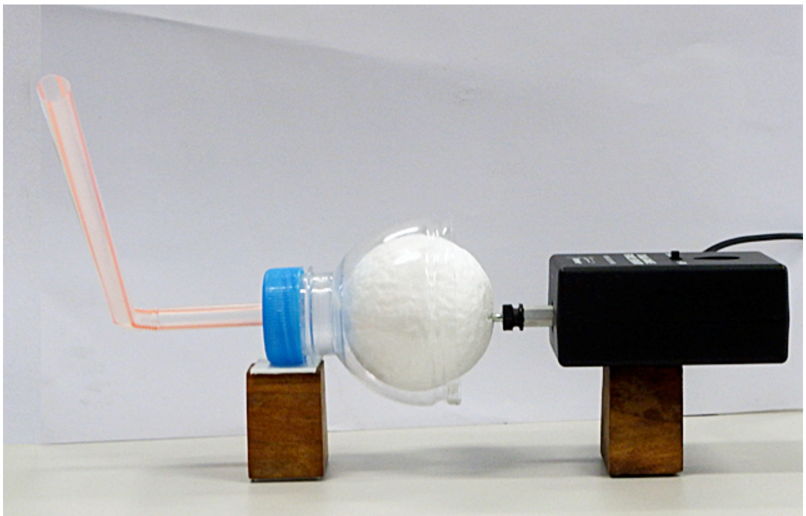

Fig 1 – force probe, ball and hemispherical cover mounted on a blocks on bench with double sided foam tape.

Following an intake of breath, around three litres of air may be forcefully expelled from the lungs. The actual amount can be measured by blowing up a plastic bag and finding the volume, or by collecting exhaled air over water in an inverted graduated cylinder. Blowing through the straw in figure 1 sets up tangential airflow over the ball that generates a horizontal force (to the left in figure 1) that can be measured with the force probe. If the exhale-rate is relatively constant the velocity of the air moving over the surface of the ball is inversely proportional to the blow time.

Figure 2 shows the force on the ball as a function of time when three litres of air are exhaled on one second.

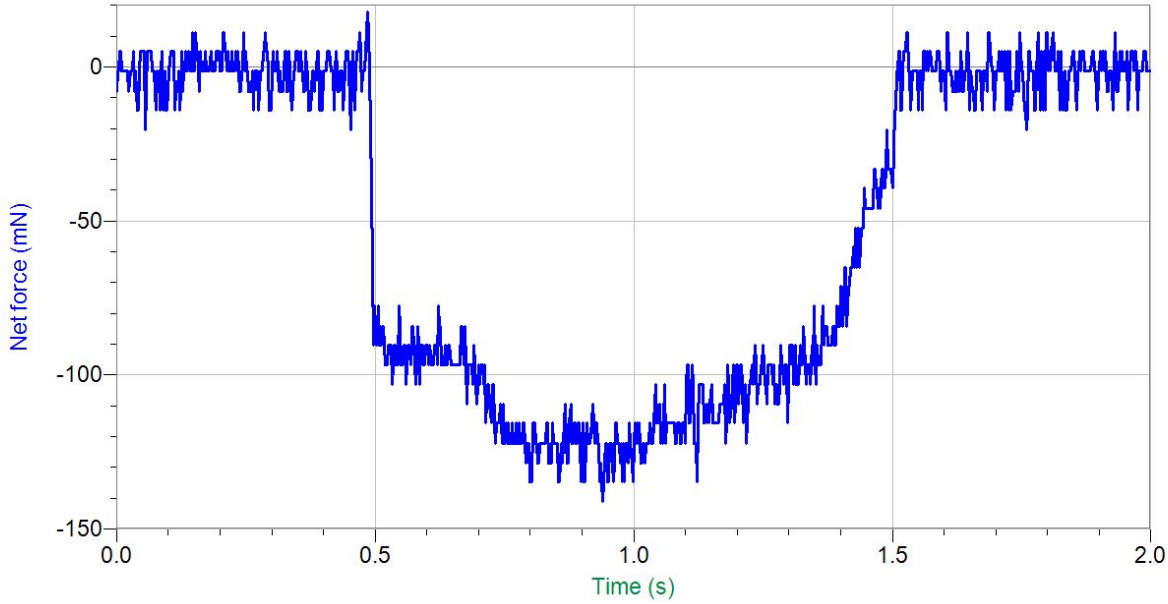

Fig 2 – force versus time as air is blown through the straw.

Exhaling the same volume of air for different times greatly changes the measured force as shown in figure 3.

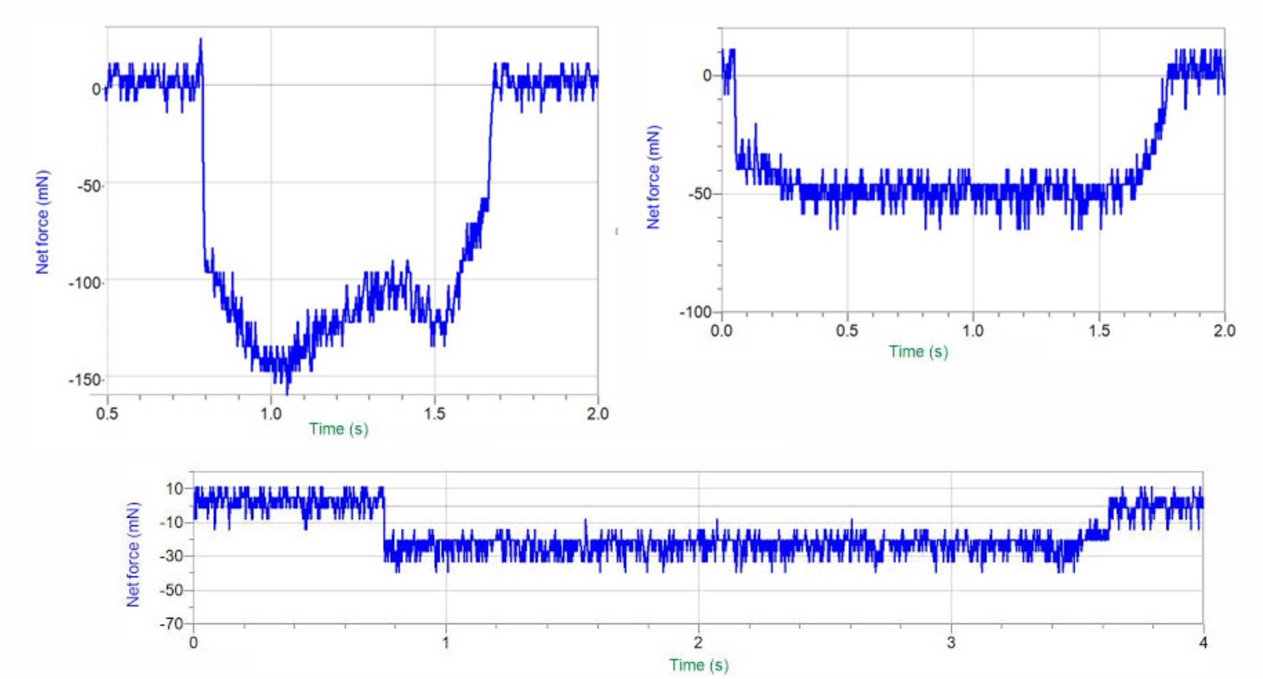

Fig 3 – force versus time plots as air is blown through the straw at different speeds.

A plot of preliminary sample data is shown below.

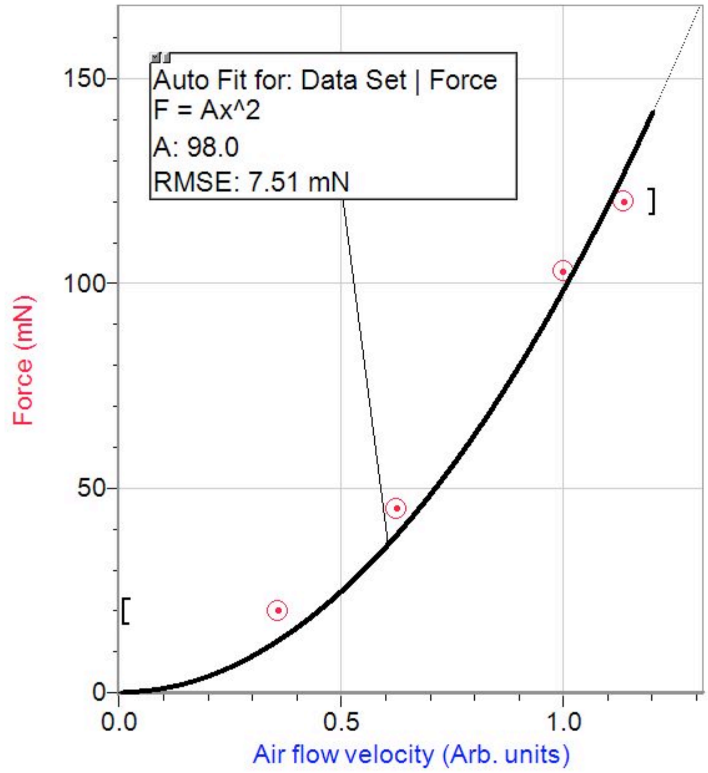

Fig 4 – measured force versus velocity of airflow in arbitrary units.

Relative velocities have been calculated as the reciprocal of the blow duration and average forces have been found from each of four plots in Logger Pro.

Measurements

1 *Mount apparatus on blocks as shown in figure 1.*

2 *Select one person to repeatedly breathe in and exhale steadily through the straw to make a series of Logger pro force/time graphs with a wide range of forces.*

3 *Plot a graph similar to figure 4 and discuss your findings***.**

Pressure reduction and force estimates

The flow velocity over the ball varies as the inverse of the area of a ring 5 mm wide between the ball and the outer cover. This cross sectional area increases with angle to reach a maximum at 90°. Integration is required to estimate the velocity of the airflow and to quantify the horizontal force that results. Faster flow over the inner end of the ball results in a larger local pressure difference (proportional to velocity squared) and at low angles the horizontal component of the resulting force is also relatively greater.

The development of a quantitative model is left as an exercise for more able students.