The Bernoulli effect

Bernoulli's equation in simple form where the symbols have their usual meanings.

$$P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y_2 = P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1 \qquad \ldots [1]$$

Each term has the units of energy density in joules per cubic metre. The equation describes the conservation of energy in laminar flow. In horizontal flow the potential energy density terms are the same ($y_1 = y_2$) and the equation simplifies to give the pressure difference ($P_2 - P_1$) as …

$$(P_2 - P_1) = \tfrac{1}{2}\rho\,(v_1^2 - v_2^2) \qquad \ldots [2]$$

Pressure is reduced when water or air flows over a surface. *The equation has been derived in ideal laminar flow, but pressure reduction occurs also in turbulent flow and the equation then gives an approximate value for the magnitude of the force per unit area.* In the demonstrations below, air flow is turbulent, and calculations based on Bernoulli's equation provide a first approximation for the forces.

Demonstrations

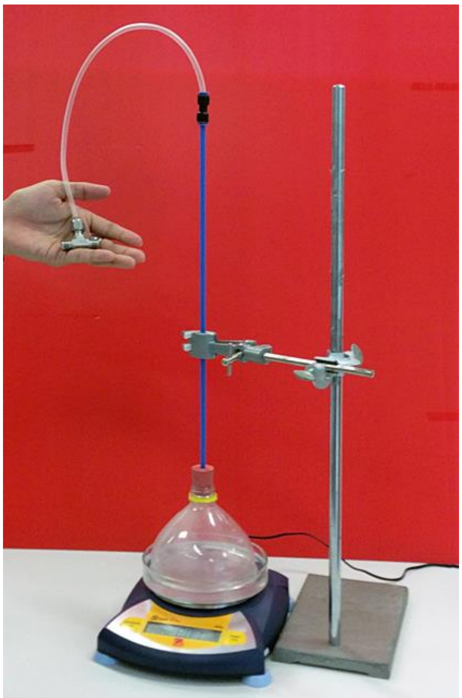
1 Reduction in air pressure due to airflow over a surface is demonstrated by blowing between two hanging balls.

Balls hang on strings.

The balls may be brought together by blowing between them. The images on the right have been taken from a video clip.

https://goo.gl/N8p6nz

2 Pressure is reduced in the half-bottle as air is blown through the T junction. Water rises inside the chamber and the reading on the balance approaches - 60 g as the airflow velocity is increased.



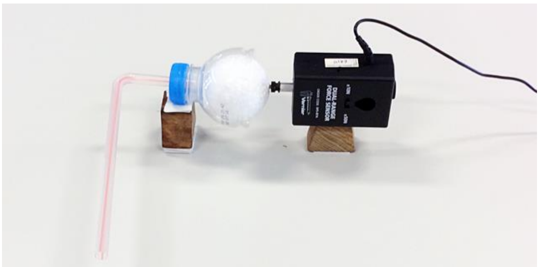
The flow is turbulent but an estimate of airflow velocity can be made from the weight reduction and the area of water inside the chamber.

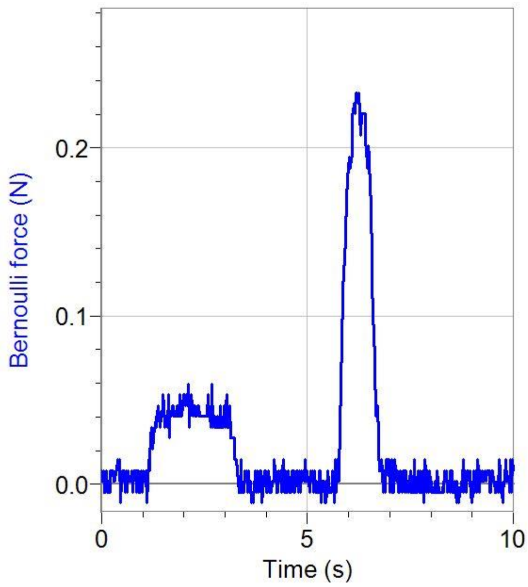
3 Frisbee was the name of a pie company that supplied pies to Yale University in the 1950’s. In 1957, students at Yale were having fun after dinner throwing empty pie tins stamped with the company's logo. The makers of a flying disc, called at the time a Pluto–Platter, noticed what was happening and renamed their toy “Frisbee”. That name has stuck ever since. Frisbees are convex on the upper surface. Faster airflow above generates lift. Concentric rings have been added on the upper surface to stabilize flight and the outer rim has been thickened to increase the moment of inertia but the principle is best demonstrated indoors with paper plates.

Two spinning plates back to back appear to “float” when the upper surface is convex. Two plates face to face cannot be made to “float” when thrown horizontally and plates don’t fly at all well convex side down.

4 Expanded polystyrene balls rest in cups. (*We have three blowers and one skeptic*.)

The balls *cannot* be blown out of the cups because fast moving air lowers air pressure on the lower surface. Turning the cups over allows the balls to be held in place by blowing through the straw. The force due to the Bernoulli effect can be measured with a force probe.





'Emptying' the lungs over 2.0 seconds when the gap between the ball and the bottle is ~ 5 mm gives a small force of 0.05 N. Emptying the lungs in half the time (1.0 s) increases the force by about four times as expected.

5 Blowing makes a small plastic ball wobble about above the basket because, as it moves to the side, faster vertical airflow reduces air pressure on the inner surface and the ball is returned towards the central line.

The ball can be lifted upwards from the basket by blowing, but not from a cup.

6 When a flexible corrugated plastic drainpipe with a diameter of 4 cm is swung in a circle it ‘sings’ with a number of harmonics that are excited within the pipe as air flows outwards past the corrugations. Closing the inner end of the pipe stops the airflow and the pipe is silent.

Data points on the outer circle show the tube position at intervals of one thirtieth of a second. It is tempting to say that airflow outwards through the pipe is due to a lowering of pressure at the outer end because air is passing over the open end of the pipe with velocity *v* (Bernoulli’s principle).

Preliminary measurements

The tube was closed at the inner end with a rubber bung. A short length of aquarium hose passed through the bung and into a bottle of water.

Swinging one metre of pipe at eight radians per second raises the water in the aquarium hose by about 30 mm indicating that the motion lowers the pressure in the closed pipe by about 300 Pa. Holding the open end of the pipe at right angles out the window of a car driven at 8 m/s raises the water in the aquarium hose by 4-5 mm (40-50 Pa) due to the Bernoulli effect. The pipe in the moving car remains silent when the inner end is opened.

For the pipe in the car the Bernoulli equation simplifies to …

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

Taking the density of air as 1.2 kg/m^3 and the air speed as 8 m/s gives …

$$\Delta P = \sim 40 \text{ Pa}$$

The calculated pressure due to the Bernoulli effect is in approximate agreement with the observed pressure in spite of the flow past the open end being turbulent. The airflow in the swinging open pipe is mostly a consequence of the outward inertial force in the accelerated frame of reference.

Additional comments

To demonstrate to oneself that air is flowing through the pipe put the inner end against your ear. Swing the pipe and feel the rush or air over your outer ear.

Airflow due to each effect can be measured by closing an inflated plastic bag over the inner end and noting the time taken to deflate the bag in a moving car and when swinging. Measurements of airspeed in the pipe under different conditions could also be made with an anemometer.