Bernoulli's Principle

Bernoulli's Principle states that as the speed of a moving fluid increases, the pressure within the fluid decreases.

Introduction

The Bernoulli's Principle explains the behavior of an ideal fluid passing through a pipe or enclosed passageway such a pump.

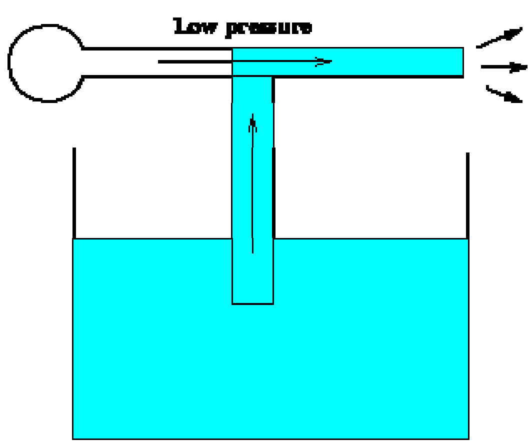
Bernoulli's principle says that a rise (fall) in “static” pressure in a flowing fluid will always be accompanied by a decrease (increase) in the speed of the fluid, and conversely, an increase (decrease) in the speed of the fluid results in a decrease (increase) in the “static” pressure.

Background Theory

To understand how and why Bernoulli's Principle works, we can consider several examples.

As a very trivial example, Bernoulli’s principle is responsible for the fact that a shower curtain gets “sucked inwards” when the water is first turned on. What happens is that the increased water/air velocity inside the curtain (relative to the still air on the other side) causes a pressure drop. The pressure difference between the outside and inside causes a net force on the shower curtain which sucks it inward

A more useful example is provided by the functioning of a perfume bottle: squeezing the bulb over the fluid creates a low pressure area due to the higher speed of the air, which subsequently draws the fluid up. This is illustrated in the following figure.

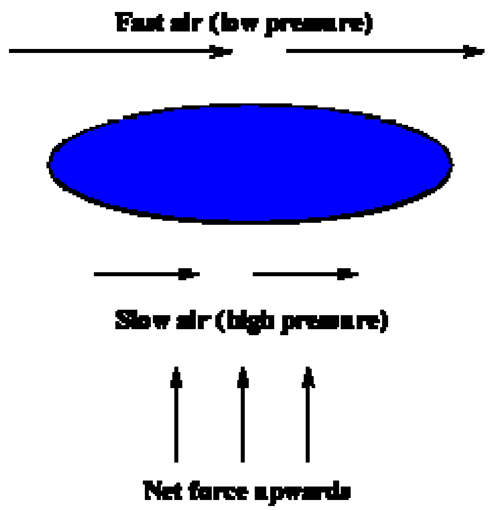


Action of a spray atomizer

Bernoulli’s principle also tells us why windows tend to explode, rather than implode in hurricanes: the very high speed of the air just outside the window causes the pressure just outside to be much less than the pressure inside, where the air is still. The difference in force pushes the windows outward, and hence it explodes. If you know that a hurricane is coming it is therefore better to open as many windows as possible, to equalize the pressure inside and out.

Another example of Bernoulli's principle at work is in the lift of aircraft wings and the motion of ``curve balls'' in baseball. In both cases the design is such as to create a speed differential of the flowing air past the object on the top and the bottom - for aircraft wings this comes from the movement of the flaps, and for the baseball it is the presence of ridges. Such a speed differential leads to a pressure difference between the top and bottom of the object, resulting in a net force being exerted, either upwards or downwards. This is illustrated in the following figure.

Lift of an aircraft wing



Applying Principle to Fluid Applications

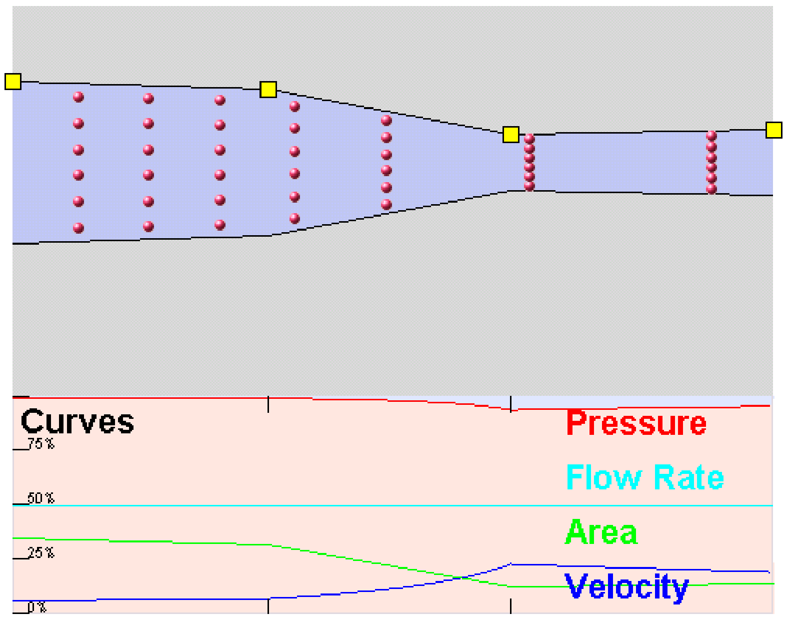
The fluid can be either a liquid or a gas. For Bernoulli's Principle to apply, the fluid is assumed to have these qualities:

- Fluid flows smoothly
- Fluid flows without any swirls (which are called "eddies")
- Fluid flows everywhere through the pipe (which means there is no "flow separation")
- Fluid has the same density everywhere (it is "incompressible" like water)

As a fluid passes through a pipe in which the diameter of the pipe narrows or widens, the velocity and pressure of the fluid vary.

In the diagram below, as the pipe narrows:

- The fluid flows more quickly (i.e., the velocity increases). See dark blue line in diagram below.
- Surprisingly, Bernoulli's Principle tells us that as the fluid flows more quickly through the narrow section, the pressure actually decreases rather than increases! See red line in diagram below.
- The gallons per minute (flow rate) remain the same. See blue line below.
- The cross section area of the pipe decreases as the diameter of the pipe narrows. See green line in diagram below.



Note: Drawing from Wikipedia encyclopedia. See www.wikipedia.com from more advanced discussion involving formulas

Ram Pressure and Static Pressure

Take a room full of children, and ask each child to start running at top speed. Children will start bouncing off each other, and the walls, with impressive collisions (ouch!).

Now take those same children out of the room, and ask them to run down the hall at top speed. Now they are all running together, and all collisions between children are much more gentle than before since they are all running in the same direction.

The children in both cases represent the atoms in the fluid, and the force of the collisions represents the pressure between those atoms. In the first case, when the speed of the group as a whole was zero, the jostling (or pressure) was high. In the second case, when the speed of the group as a whole was large, the jostling (or pressure) was low.

In this article when we refer to *pressure*, we actually mean static *pressure*, which is the pressure felt by an object suspended in the fluid and moving with it. This pressure is static because the suspended object is not moving relative to the fluid. In this section only we will discuss another other type of pressure: *ram pressure*.

Static pressure should not be confused with ram pressure, which is the pressure felt by an object because it is moving relative to the fluid. Basically, the fluid is ramming into the moving object, or vice versa.

The ram pressure **increases** when the speed **increases**. This explains the stronger force felt by your hand when it is held a fast moving current. In the faster current, your hand is deflecting more flowing fluid from its original path.

As you wade across a rushing stream, the force against your legs is from the ram pressure, and it is directed downstream.

The static pressure **decreases** when the speed **increases**, as explained in the Background Theory section above. This explains why the water stream coming out of a firefighter's hose gets narrower a short distance past the nozzle - the stronger atmospheric pressure overwhelms the weaker static pressure in the quickly flowing water and compresses the water stream.

Fundamental Relationships

This is an important principle involving the movement of a fluid through a pressure differential. Suppose a fluid is moving in a horizontal direction and encounters a pressure differential. This pressure differential will result in a net force, which by Newton's 2nd law will cause an acceleration of the fluid.

The fundamental relation is:

Work done = Change in Kinetic Energy

This can be expressed as:

(Change in Pressure) x Area x Distance = Change in Kinetic Energy.

Which furthermore can be expressed as:

(Change in Pressure) + Change in (Kinetic Energy/Volume) = 0.

In other words,

Pressure + (Kinetic Energy/Volume) = Constant

which is known as **Bernoulli's principle**.

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