Fluids
Applications of Fluid Dynamics

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Last time

- fluid dynamics
- the continuity equation
- Bernoulli's equation

Overview

- Torricelli's law
- applications of Bernoulli's equation

Bernoulli's Equation and the Continuity Equation

A law discovered by the 18th-century Swiss scientist, Daniel Bernoulli.

Bernoulli's Principle

As the speed of a fluid's flow increases, the pressure in the fluid decreases.

The Continuity equation:

$$A_1 v_1 = A_2 v_2$$

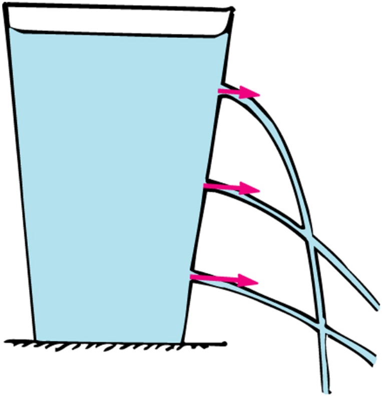
Bernoulli's Equation:

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{const}$$

is constant along a streamline in the fluid.

Torricelli's Law from Bernoulli's Equation

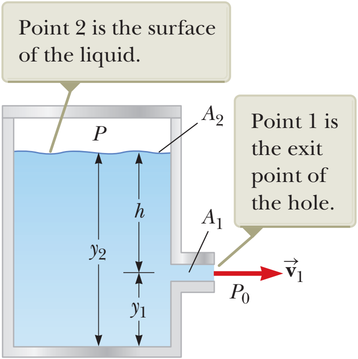
Bernoulli's equation can also be used to predict the velocity of streams of water from holes in a container at different depths.



Torricelli's Law from Bernoulli's Equation

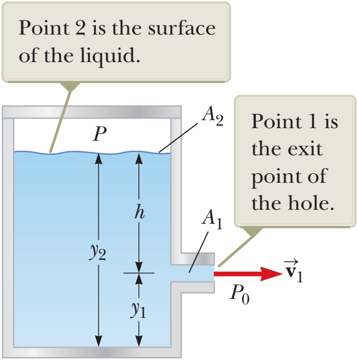
The liquid at point 2 is at rest, at a height y_2 and pressure P.

At point 1 is leaves with a velocity v_1, at a height y_1 and pressure P_0.



$$\frac{1}{2}\rho v_1^2 + \rho g y_1 + P_0 = \frac{1}{2}\cancelto{0}{\rho v_2^2} + \rho g y_2 + P$$

Torricelli's Law from Bernoulli's Equation

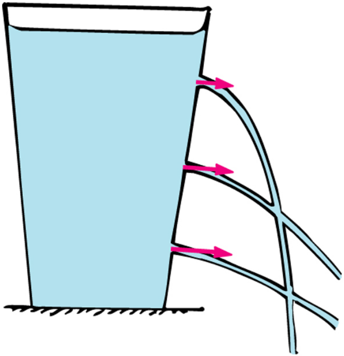


$$\frac{1}{2}\rho v_1^2 + \rho g y_1 + P_0 = \rho g y_2 + P$$

Rearranging, and using $y = h_2 - h_1$,

$$v_1 = \sqrt{\frac{2(P - P_0)}{\rho} + 2gh}$$

Torricelli's Law from Bernoulli's Equation



Notice that if the container is open to the air $(P = P_0)$, then the speed of each jet is

$$v = \sqrt{2gh}$$

where h is the depth of the hole below the surface.

Implications of Bernoulli's Principle

Bernoulli's principle also explains why in a tornado, hurricane, or other extreme weather with high speed winds, windows blow *outward* on closed buildings.

Implications of Bernoulli's Principle

Bernoulli's principle also explains why in a tornado, hurricane, or other extreme weather with high speed winds, windows blow *outward* on closed buildings.

The high windspeed outside the building corresponds to low pressure.

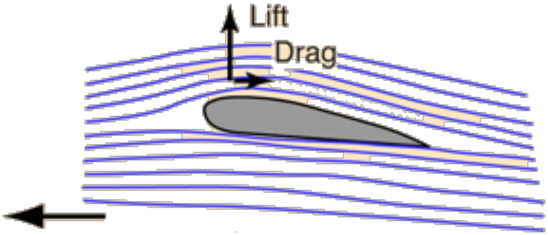
The pressure inside remains higher, and the pressure difference can break the windows.

It can also blow off the roof!

It makes sense to allow air a bit of air to flow in or out of a building in extreme weather, so that the pressure equalizes.

Implications of Bernoulli's Principle

Bernoulli's principle can help explain why airplanes can fly.



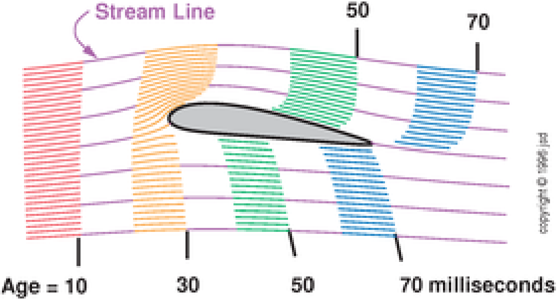
Air travels faster over the top of the wing, reducing pressure there.

That means the air beneath the wing pushes upward on the wing more strongly than the air on the top of the wing pushes down. This is called **lift**.

[1] Diagram from HyperPhysics.

Air Flow over a Wing

In fact, the air flows over the wing much faster than under it: not just because it travels a longer distance than over the top.



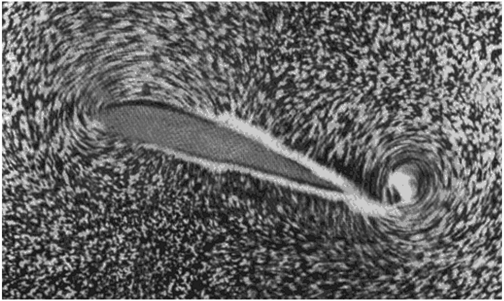
This is the result of circulation of air around the wing.

[1]Diagram by John S. Denker, av8n.com.

Air Flow over the Top of the Wing: Bound Vortex

A starting vortex trails the wing. The bound vortex appears over the wing.

Those two vortices counter rotate because angular momentum is conserved.



The bound vortex is important to establish the high velocity of the air over the top of the wing.

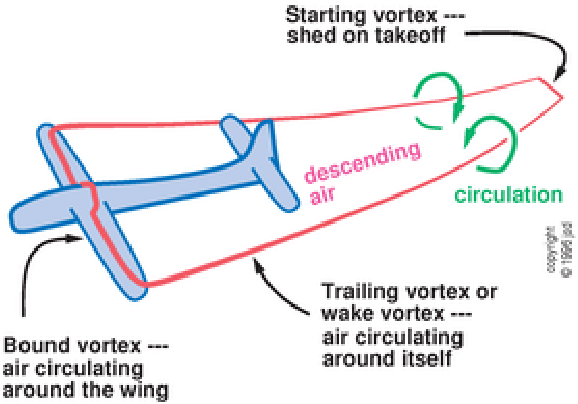
[1] Image by Ludwig Prandtl, 1934, using water channel & aluminum particles.

Wingtip Vortecies

Other vortices also form at the ends of the wingtips.

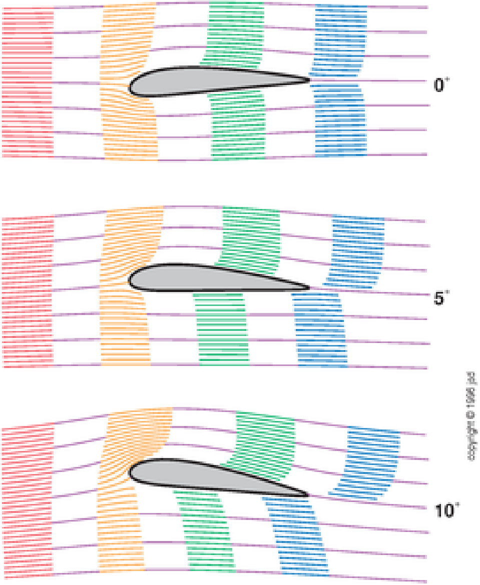
[1]Photo by NASA Langley Research Center.

Vortices around an Airplane



[1]Diagram by John S. Denker, av8n.com.

Airflow at different Angles of Attack

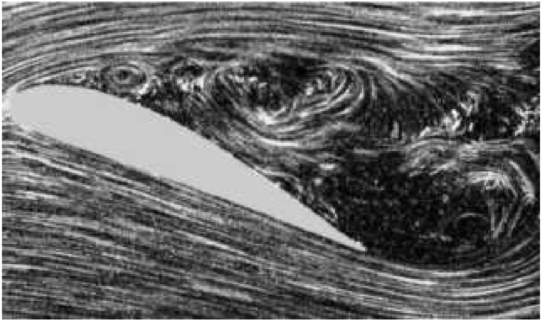


[1]Diagram by John S. Denker, av8n.com.

Implications of Bernoulli's Principle

A **stall** occurs when turbulence behind the wing leads to a sudden loss of lift.

The streamlines over the wing detach from the wing surface.



This happens when the plane climbs too rapidly and can be dangerous.

[1]Photo by user Jaganath, Wikipedia.

Implications of Bernoulli's Principle

Spoilers on cars reduce lift and promote laminar flow.

[1]Photo from http://oppositelock.kinja.com.

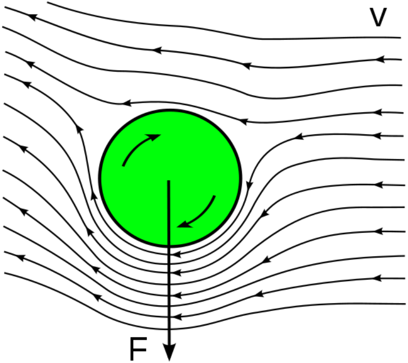
Implications of Bernoulli's Principle

Wings on racing cars are inverted airfoils that produce *downforce* at the expense of increased drag.

This downforce increases the maximum possible static friction force $\Rightarrow$ turns can be taken at higher speed.

[1]Photo from http://oppositelock.kinja.com.

Implications of Bernoulli's Principle



A curveball pitch in baseball also makes use of Bernoulli's principle.

The ball rotates as it moves through the air.

Its rotation pulls the air around the ball, so the air moving over one side of the ball moves faster.

This causes the ball to deviate from a parabolic trajectory.

[1]Diagram by user Gang65, Wikipedia.

Summary

- Torricelli's law
- applications of Bernoulli's equation

Test! tomorrow, in class.

(Uncollected) Homework

Serway & Jewett:

- study for the test