

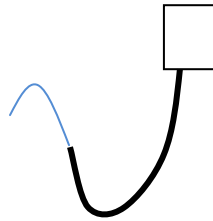
If we can come to understand how energy changes as a fluid flows, we can come to understand how planes fly, how rockets work, etc.

Cause of fluid flow: Fluid flow is caused by  $\Delta P$ , a pressure difference between two locations, assuming they are at the same height. (If you try moving water uphill, you're also fighting gravity). The principle here is that fluids accelerate toward low pressure.

Suck on straw, blow on straw. Where is higher pressure location? Where is low pressure location?

GPE, PPE, KE: Squeeze on bottle, it increases the pressure. Work done is very small, because liquids are pretty much incompressible. So I'm giving the water in the bottle what some refer to as "Pressure Potential Energy," The energy here is potential, because although there's pressure, it's not doing anything. However, if you open the top, that PPE results in... KE (water moving fast), and as the water rises, its KE transforms to GPE. These are the 3 forms of energy we'll investigate in fluids as they flow, either through pipes or freely in the environment.

We can see this clearly with an elevated container, with a hose, that has an exit here... If the container is at the same level as the opening, no water comes out. There's no GPE relative to the opening, so we get no KE at the exit. If you do work on the water, raise it up, you are giving it GPE. Then the GPE ends up as KE at the opening... but what happens in the middle? At the lowest point in the hose, we have high pressure, PPE. It's like being deep under water. The higher the water, the higher the pressure at the bottom, and thus the higher the water spurts out. The fluid flows from the area of higher pressure to lower.



Conservation of energy in fluids: In a certain context, the energy contained in a moving fluid is the sum of 3 parts, GPE, PPE, KE. The principle behind this conservation of energy in fluids is Bernoulli's principle. Of course, we must be aware of the "certain context". Under what circumstances is this true? There are 2.

Steady State flow: if you look at the fluid, it has no apparent change in time. You can't tell by looking what time it is. There are no air bubbles, no paddles, etc. This ensures that NO WORK is being done by anything that is in contact with the fluid. (just like energy of solid objects, if you push on the object, you can add or subtract energy).

In a streamline: you are following a section of the fluid with the same history. It has to be the "same fluid". You can't compare what's going on in your pipes to what's going on in a soda bottle. The water has to have the same history. If the streamlines get crossed over each other (turbulence), something is doing work on that fluid which causes energy loss due to frictional heating. So you need a streamlined flow. "Laminar flow".

So assuming we've got these conditions met, we can examine all the possible energy changes that can take place. (there are 6)

GPE  $\rightarrow$  KE: waterfall

KE → GPE: fountain

KE → PPE: car washing – moving water hits a surface

PPE → KE: nozzle

PPE → GPE: water being pushed uphill by a pump (as in a well)

GPE → PPE: water tower

Continuity principle: In a closed system, volume flow rate is constant.  $V/t = \text{constant}$ , where  $V = \text{Volume}$

$v_1A_1 = v_2A_2$  ( $v$  is velocity, not Volume). Note that units of  $V/t$  and  $vA$  are equivalent.

Example problem:

Viscosity: Self-stickiness of a substance. Resistance of the molecules of a substance to slide past one another. Honey > Oil > water. Greek letter “eta”:  $\eta$ . Like a lower case “n” but with a long ending tail. Viscosity is not the same property as density. Density is mass per volume, and is independent of the “thickness” of the fluid. Viscosity is essentially “thickness”. Water is more dense than oil, but less viscous. More viscous fluids flow more slowly, yet are less inclined to experience turbulence (more on that later).

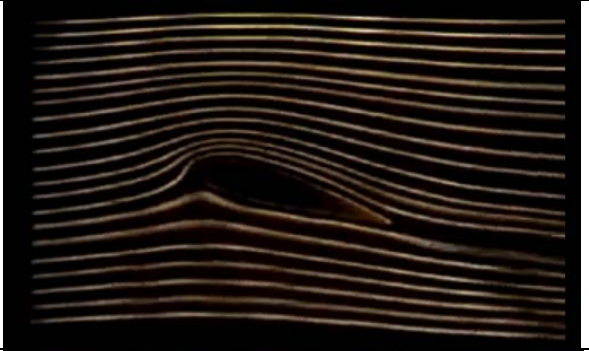


Poiseuille’s Law: We must acknowledge that viscosity exists, and so we can revisit the idea of Volume flow rate. The continuity principle still holds, but now that there’s friction, things won’t be going as fast as a viscosity-free fluid would.

$$\frac{V}{t} = \frac{\pi \Delta P d^4}{128 L \eta}$$

Let’s evaluate each term in the equation and think about why it makes sense. If you increase the pressure difference (push harder) of course you increase the flow rate. If you increase the diameter of the pipe, flow increases. (how would you feed water to a city, through a 10m pipe, or a garden hose?). If you increase the Length of the pipe, that’s more total surface area in contact (more friction, essentially), and if you increase the viscosity (thickness) of the fluid, you slow down the flow. All very intuitive and sensible.

Turbulent vs. laminar flow, Boundary Layer:

The boundary layer is the thin layer of the fluid that is directly in contact with the surface. This boundary layer can be in 1 of 3 states, which will directly affect the kinds of drag forces experienced by the object.

	<p>Boundary layer is: laminar, attached.</p> <p>The boundary layer is moving smoothly over the surface of the wing, and follows the contour of the wing exactly. Viscous drag is dominant here, because the only slowing force is due to the fluid trying to slide past the material of the wing.</p>
	<p>Boundary layer is turbulent, attached.</p> <p>The immediate upper surface of the wing has a thin layer of turbulent air above it, but the air just above <i>that</i> still flows as though it's moving over a wing surface. The laminar parts of the fluid move as if it were passing over a slightly thicker wing, because the turbulent, attached boundary layer behaves as an extension of the wing surface. Pressure drag begins to be a large factor.</p>
	<p>Boundary layer is turbulent, detached.</p> <p>The air flowing over top of the wing is completely separated from the wing itself. Behind the wing is an area of great turbulence. Pressure drag is dominant here, since there is enormous high pressure on the bottom surface of the wing, and the turbulent area to the right is very low pressure, creating a large force up and to the right.</p>

Pressure drag vs. viscous drag:

Pressure drag is due to a pressure difference between the 2 ends of an object, as in the 3<sup>rd</sup> picture above, or as in a school bus that has a large flat face hitting the wind (high pressure area) and turbulence in the back (low pressure area). The pressure difference between the front and back create a large force of “air resistance”. This is what the phrase “air resistance” is referring to. Pressure drag is what making an “aerodynamic” design hopes to reduce. Primarily affected by the shape of the front and rear of the object. A shape which “cuts” through the air, and which allows the air behind the object to gracefully reconnect with itself will have the lowest pressure drag. Dolphins and Corvettes experience low pressure drag. A school bus experiences large pressure drag.

Viscous drag is due to the fact that an object is simply trying to slide past a viscous fluid. The layer in contact with the surface must slide over the surface, and the layers above them must slide over each other, and so there is some resistance due to that effort. Primarily affected by the amount of surface area and the viscosity of the fluid. Increase either, and you increase the viscous drag.

## Inertia vs. viscosity

What determines whether turbulence begins or not? The inertia of the fluid tends to cause the fluid to keep moving in a straight line, as in picture 3 above. Viscosity tends to keep the layers of the fluid attached to each other, as in picture 1 above. If the wing were to move through a more viscous fluid, the wing could maintain laminar flow at a higher speed, because the fluid would be less apt to separate from itself and the surface of the wing. If the wing were to move through a more dense fluid (more mass per volume), inertia would dominate, and the boundary layer would detach at lower speeds.

Thus, inertia dominates turbulent airflow, ripping it apart into swirling eddies. This occurs around/behind *larger objects* and when *speeds are higher*.

Viscosity dominates laminar airflow, keeping it smooth and orderly. More likely around *smaller* or *slower moving* objects.

Reynold's #: The Reynold's number is an indicator of what type of boundary layer to expect. It's not always exactly right, because of the near infinite variability of real surfaces, but it's useful to give a general estimate about what to expect in a given situation.

$$Re = \frac{\rho Lv}{\eta}$$

If  $Re < 2000$ , boundary layer is laminar and attached – viscosity dominates

$2000 < Re < 100,000$  boundary layer is turbulent, attached – pressure drag begins to dominate

$Re > 100,000$  boundary layer is turbulent, detached – pressure drag severely dominates