PhyzGuide: Anatomy of Drag

Who's seen the wind? Not you or I.
But when the ship moves, she's passing by.

Drag. You see its effect when a dropped feather wends its way to the ground. You feel it when you stick your hand out of the car window while traveling on the highway.

Drag is a force. It's the interaction between a solid and a fluid when the two are moving relative to each other. When we study drag, we are typically interested in the force that the fluid substance exerts on the solid object.

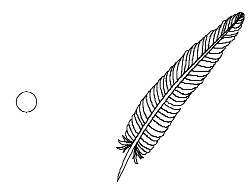
So suppose a solid object like a car moves through a fluid substance like air. What factors determine the strength of the drag force on the car?

Cross-Sectional Area (*A*). As the object moves through the fluid, it pushes the fluid directly in front of it. Therefore, the fluid pushes back on the object. The larger the object, the more fluid it pushes; the more fluid it pushes, the greater the drag. But it's not simply a matter of size. A javelin is much larger than a feather yet it suffers less drag when moving through the air. What's important is the size of the object *as it appears to the fluid that lies in front of it*. The fluid in front of the moving javelin sees the javelin as a small circle; the fluid in front of the moving feather sees the full irregular shape of the feather. We say that the javelin presents a relatively small cross-sectional area to the fluid while the feather presents a relatively large cross-sectional area. Similarly, a school bus presents a greater cross-sectional area to the air than does a sports car. (But just try to get 78 screaming first-graders into the sports car; *that* would be a drag!)

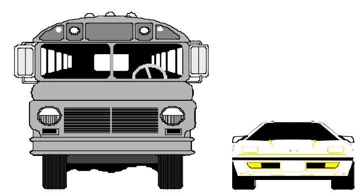
Drag Coefficient (*C*). A sleek object can "cut through the air" better than a boxy object. We sometimes talk about highly aerodynamic cars by referring to the "fluid lines" of their design. And we refer to boxy objects as air-plows. We're talking now about the geometry of the solid object. Does it allow the fluid to slip easily around it or does it push the fluid forward? Remember, the fluid will do to the solid as the solid does to the fluid. The drag coefficient is a number that quantifies the geometry of the object. A low coefficient means the object is sleek; a high coefficient means the object is boxy. The greater the drag coefficient,

Fluid means _liquid_: Fact or myth?

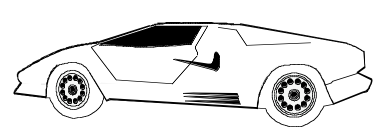
In everyday usage, the word fluid is often used in place of the word liquid. If we are sick, we are told to drink plenty of *fluids*. Our soda can claims to carry 12 *fluid* ounces. Indeed, all liquids are fluids. However, not all fluids are liquids. A fluid is a substance that can flow. So gases are fluids, too. In fact, glass is a fluid, too! We usually think of glass as a solid (and are correct to do so) but glass does have the ability to flow. We see evidence for this in windows of ancient cathedrals in Europe, where the glass has been flowing for hundreds of years. The glass at the bottom of these windows is measurably thicker than the glass at the top.



A javelin and a feather as seen by fluid lying directly in front of them.

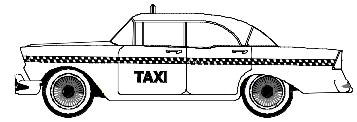


A school bus and a sports car comin' at ya.



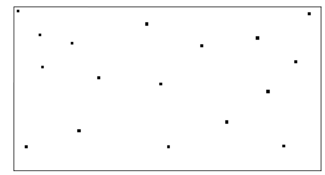
Lamborghini: a model of low drag coefficient.

the greater the drag force. So the Lamborghini has a distinct advantage over the taxi cab in terms of drag coefficient. (But just try to hail a Lamborghini on a New York City street curb...)

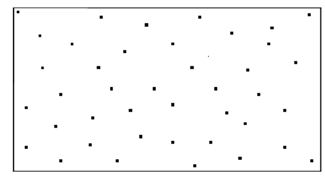


Taxi cab: not a model of low drag coefficient.

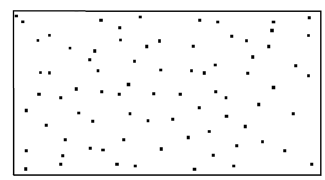
Fluid Density (ρ). Imagine riding your bike on a windless day. The breeze you feel is because you are moving through the still air. The force of that breeze on you is the drag force. Now imagine moving at the same speed through water. Big difference! But you haven't gotten any bigger (no increase in *A*). The geometry of your body hasn't changed (no increase in *C*). The dramatically greater force of drag you would encounter in the water is due to the greater density of the water. If you can imagine trying to move through the dense liquid metal mercury, you would appreciate the fact that greater fluid density results in greater drag force. You might also question mercury's nickname. Since the drag force arises from collisions between the molecules in the fluid and the surface of the solid object, an increased fluid density means the solid object will either collide with more molecules or collide with more massive molecules (or both). Either way, the drag force is increased.



Low density fluid.



A fluid with more closely packed molecules has higher density.



A fluid with heavier molecules has higher density.

Relative Speed (*v*). Compare the sensation of sticking your hand out the window of a car while it's moving at 55 mph to the sensation of sticking your hand out of the window of a car parked in the garage. Big difference. But the cross-sectional area of your hand, the geometry of your hand, and the density of the surrounding air have not changed. The difference in drag is due to the difference in the speed of your hand relative to the air. As your hand tries to make its way through the air at higher speeds, two things happen. Your hand encounters more molecules of air, resulting in increased drag. And the molecules that collide with your hand do so at a higher speed, also resulting in increased drag. So drag is "doubly" dependent on relative speed.

All Together Now. Those are the factors that determine the drag on a solid object as it moves through a fluid substance. Cross-sectional area, drag coefficient, fluid density, and relative speed. Together, they give the formula for drag.

$$D = {}^{1}/{}_{2}CA\rho v^2$$

We will "streamline" this equation for our own use by consolidating the $^1/2$, *C*, *A*, and ρ into one factor called the *aerodynamic coefficient, k*.

$$D = kv^2$$