

Wings and Things:

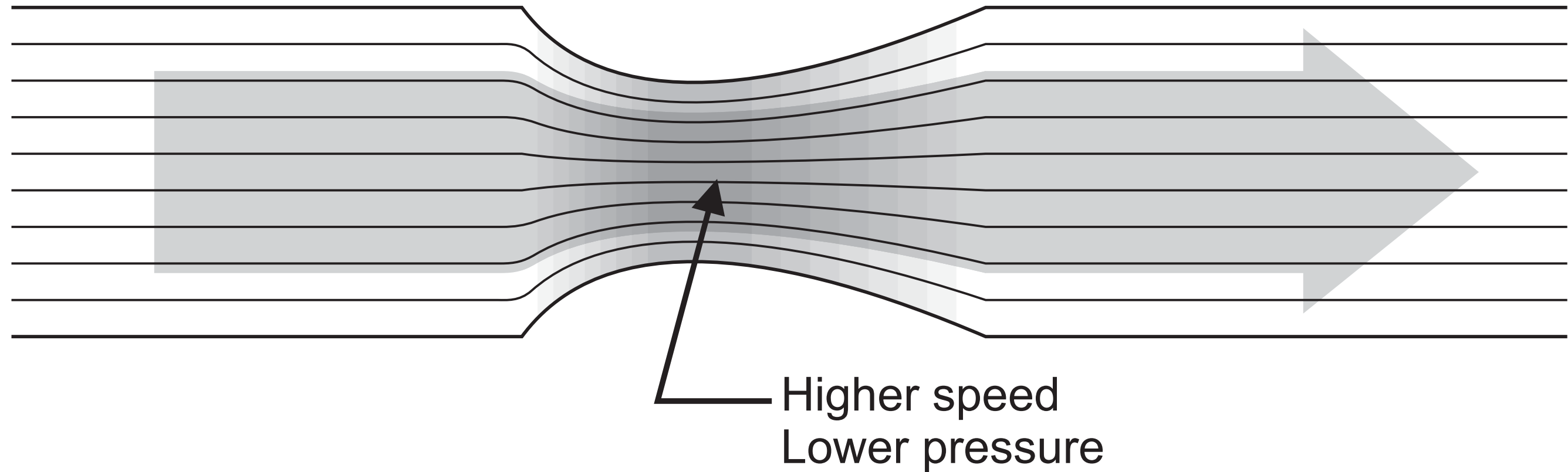
A Practical Introduction to Aeronautics

Bob Kuykendall 3 May 2007

Bernoulli's Principle

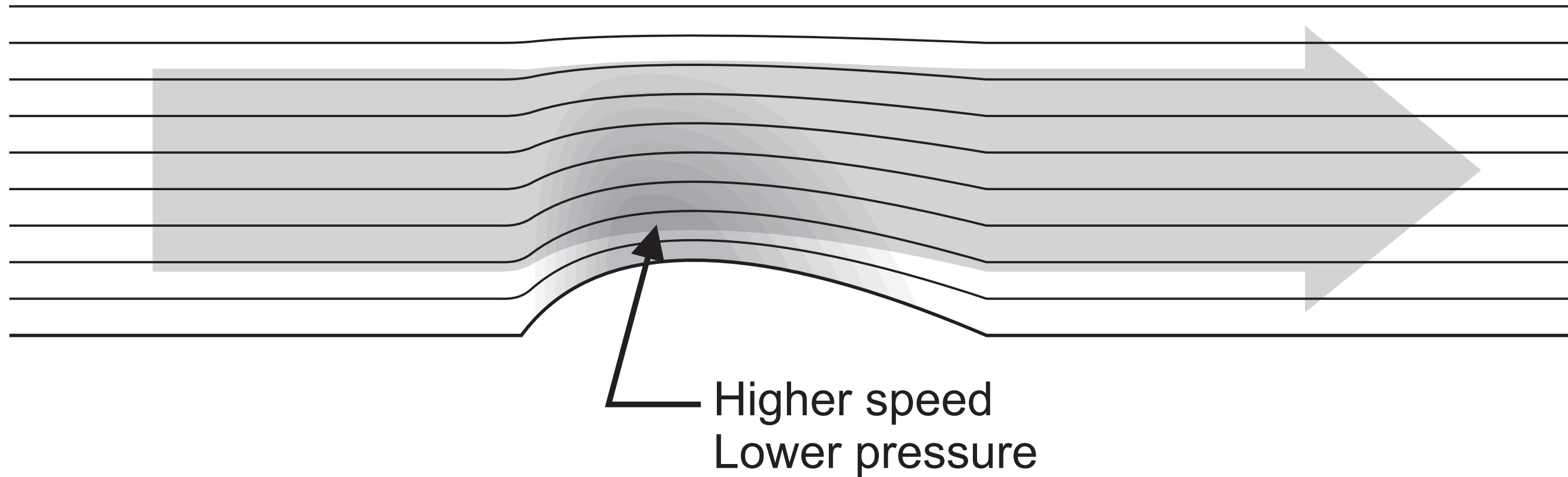
Increasing the speed of a fluid or gas decreases its pressure.

As applied to a Venturi



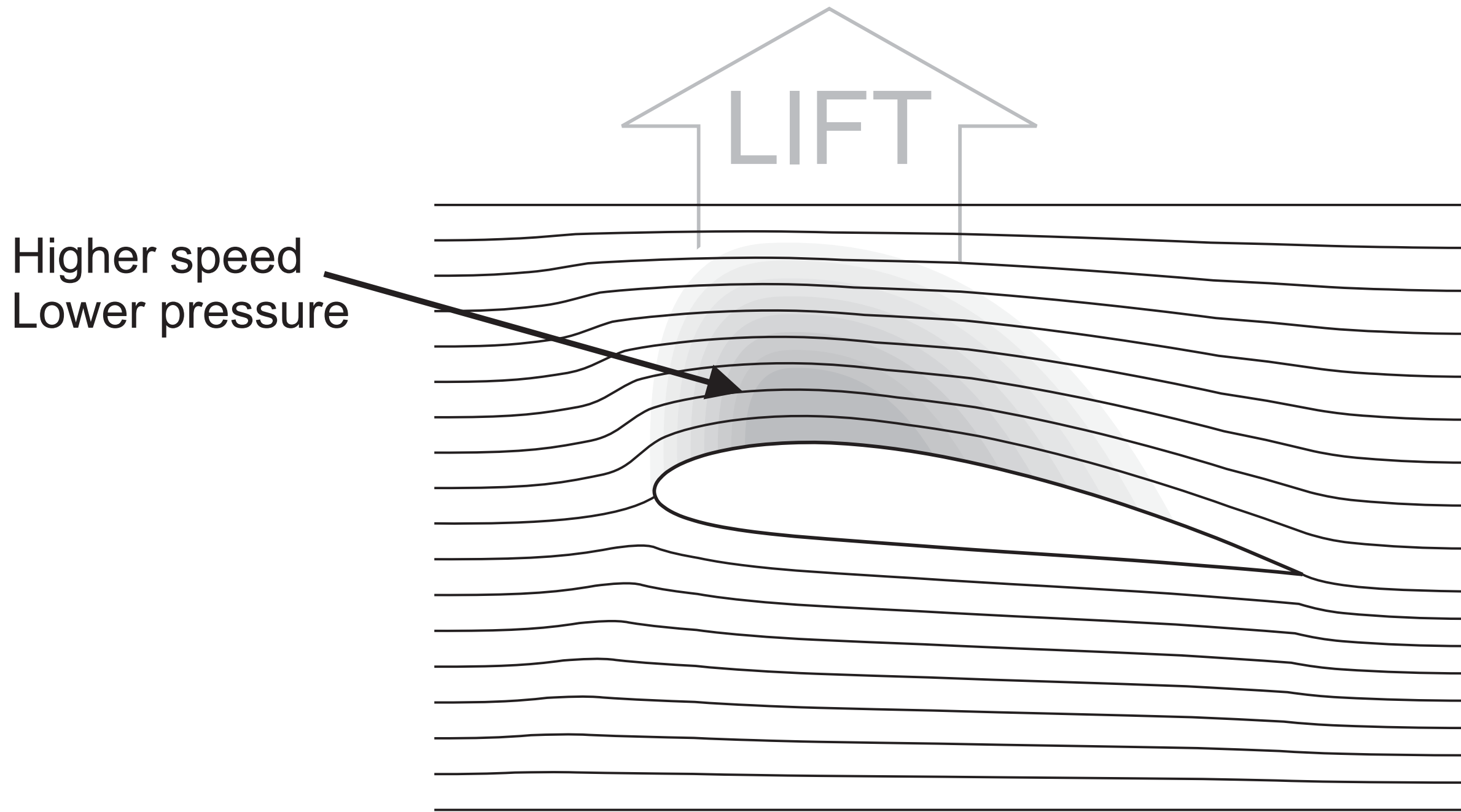
Bernoulli's Principle

As applied to half of a Venturi

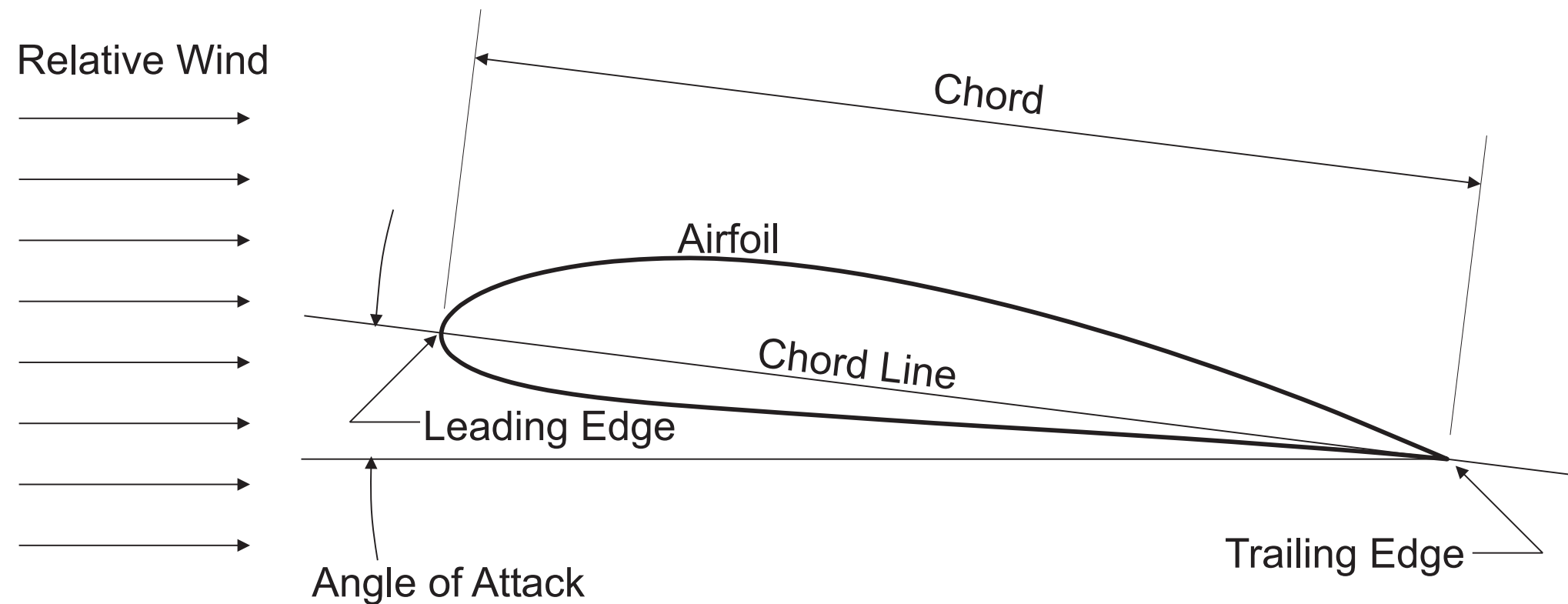


Bernoulli's Principle

As applied to an airfoil



Airfoil Terms



Airfoil - The shape used for the cross-section of a wing or other lifting surface.

Leading Edge - The front edge of the airfoil. Usually rounded.

Trailing Edge - The back edge of the airfoil. Usually sharp.

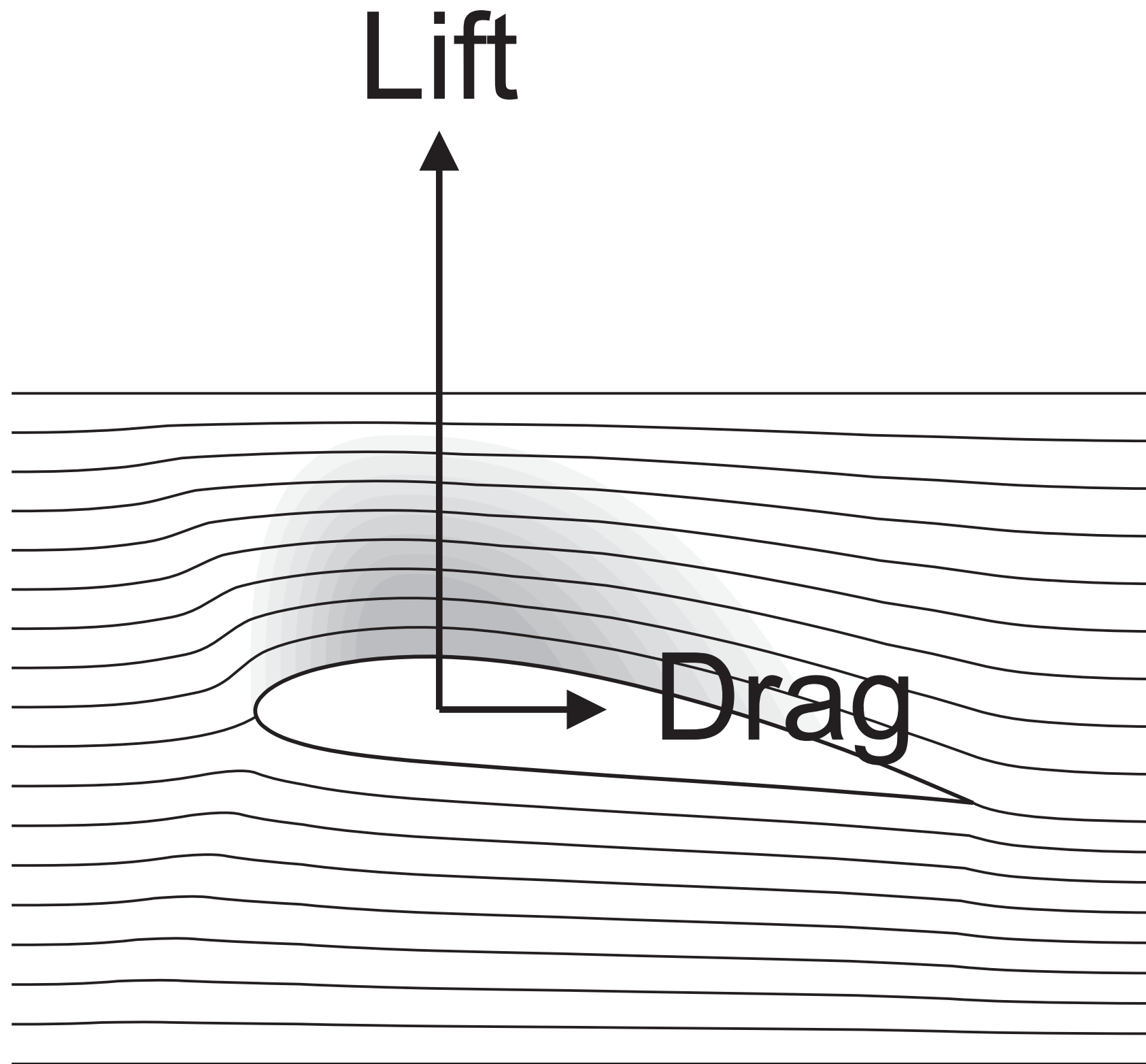
Chord - The straight-line distance between the leading edge and the trailing edge.

Chord Line - A straight line between the leading edge and the trailing edge. The chord line is used as a reference for measuring the angle of attack.

Angle of Attack - The angle between the airfoil (measured at the chord line) and the relative wind.

Relative Wind - Air moving over the airfoil, either because the air is still and the airfoil is moving, or because the airfoil is still and the air is moving.

Basic Airfoil Forces: Lift and Drag

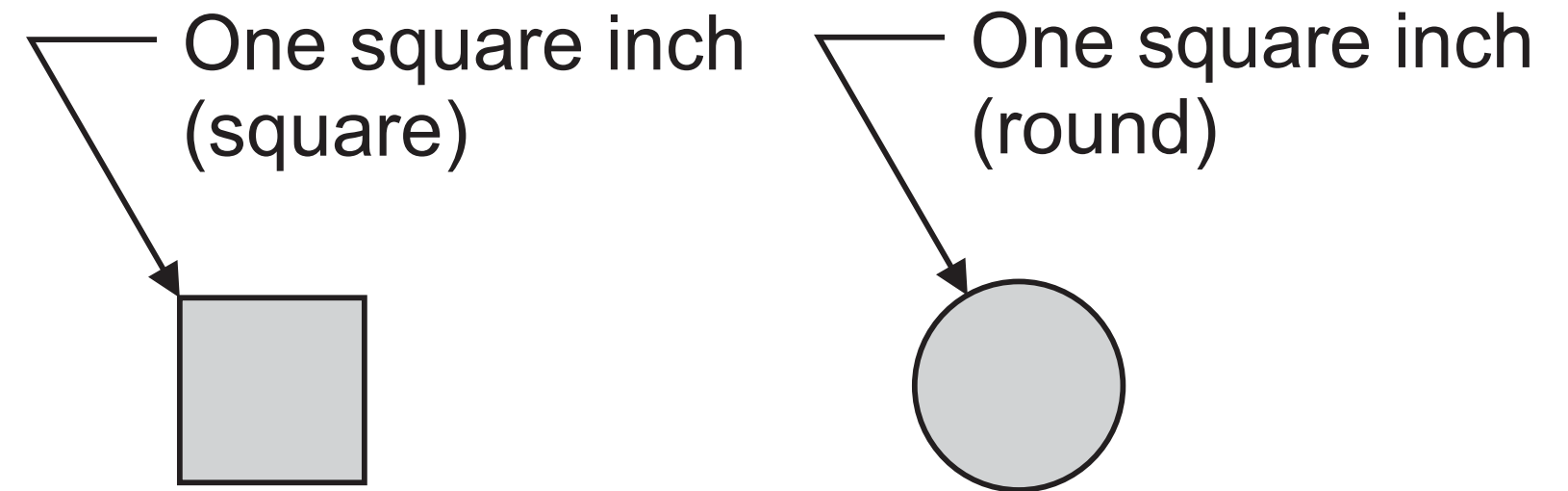


Lift - The upward pull of the airfoil at a right angle to the relative wind. Lift is caused by the pressure difference between the upper and lower surfaces of the airfoil.

Drag - The rearward pull of the airfoil parallel to the relative wind. Some drag is caused by friction between the airfoil and the air, and some is created as a byproduct of making lift.

About that pressure difference...

Pressure is a force applied over an area. For an example of pressure, think about the air inside a bicycle tire, typically around 40 PSI or pounds (the force) per square inch (the area).



Experiment Time: Lifting a Bowling Ball

Question: Suppose you have a vacuum cleaner capable of 1.2 PSI (pounds per square inch) of vacuum. Is the vacuum cleaner strong enough to lift a 12-pound bowling ball?

Experiment Time: Lifting a Bowling Ball

Answer: Yes, easily!

The 2" hose on most vacuum cleaners has a cross-section area of about 3.14 square inches.

3.14 square inches times 1.2 pounds per square inch is about 3.8 pounds. Not enough to lift the 12 pound ball.

But adding an 8" funnel to the hose increases the area to about 50 square inches. 50 square inches times 1.2 PSI is about 60 pounds, enough to lift five bowling balls!

The formula for the area of a circle is:

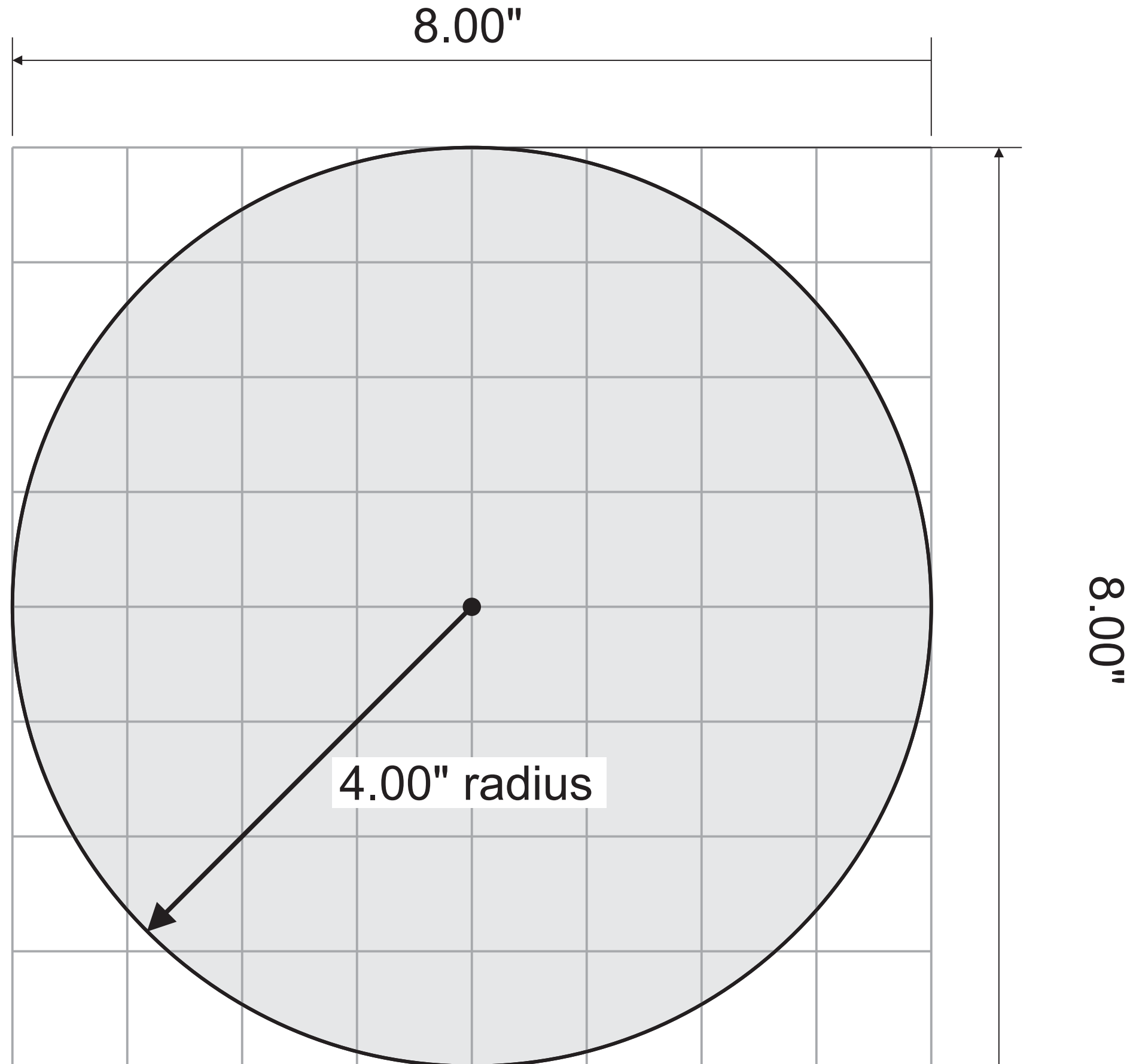
$$A = \pi * r^2$$

The area of an 8" diameter circle is:

$$A = \pi * 4^2$$

$$= 3.14 * 16$$

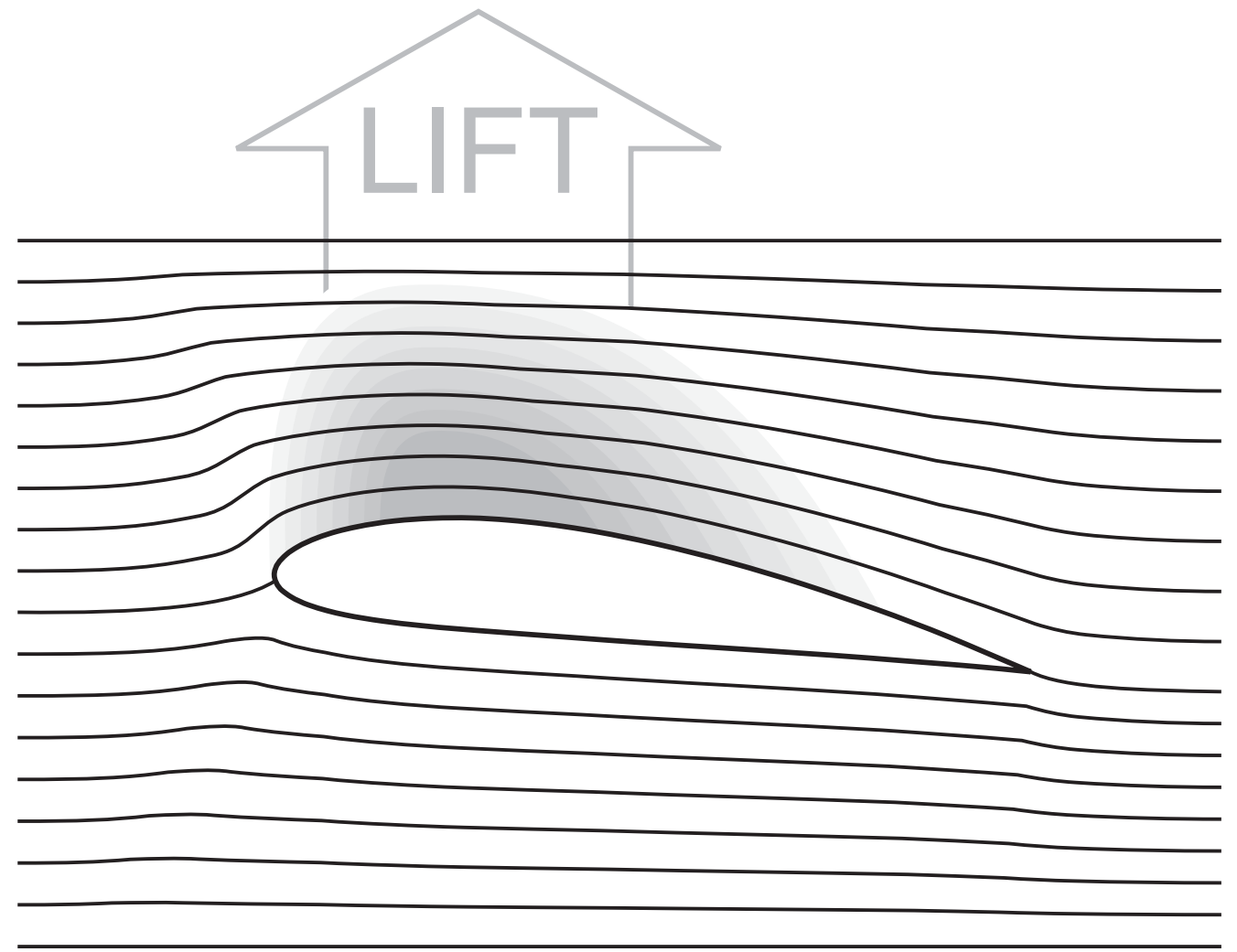
$$= 50.24 \text{ square inches}$$



Lift and Pressure Difference

A wing produces lift because its airfoil shape creates low pressure over the top surface and high pressure under the bottom surface as it moves through the air.

Question: How great does the pressure difference have to be? How big a pressure difference are we talking about?



Lift and Pressure Difference

Answer: Not very great at all!

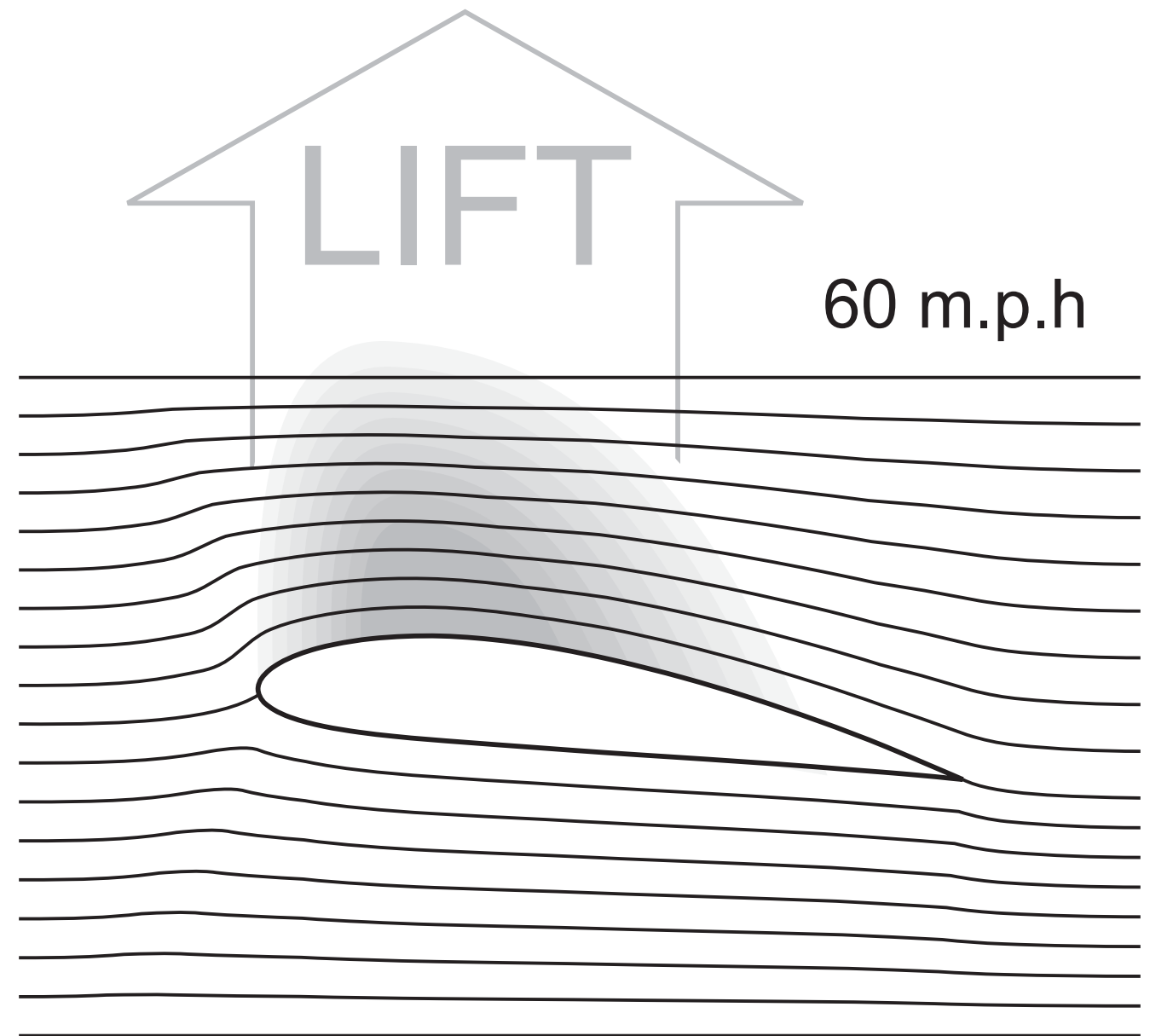
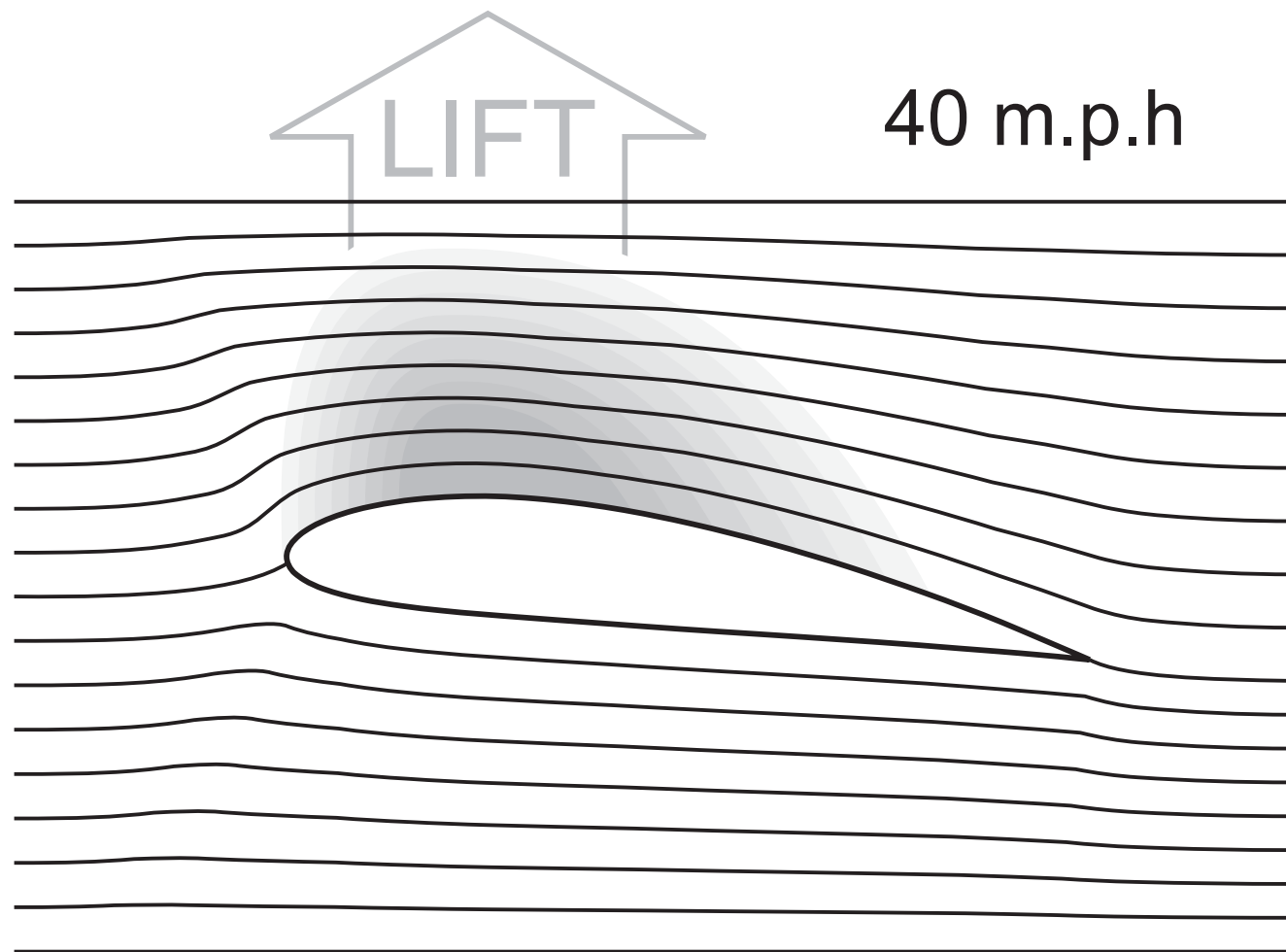
Consider a small airplane that weighs 1000 pounds, has a 20-foot wingspan and 5-foot chord. The airplane has a wing area of 100 square feet (20 X 5).

There are 144 square inches per square foot. So the airplane has a wing area of 14,400 square inches.

In order to lift off the ground, the wings only have to produce a pressure differential of $1000 / 14,400 = 0.069$ pounds per square inch. That's about 1/500th of the air pressure in a typical car tire.

Lift and Airspeed

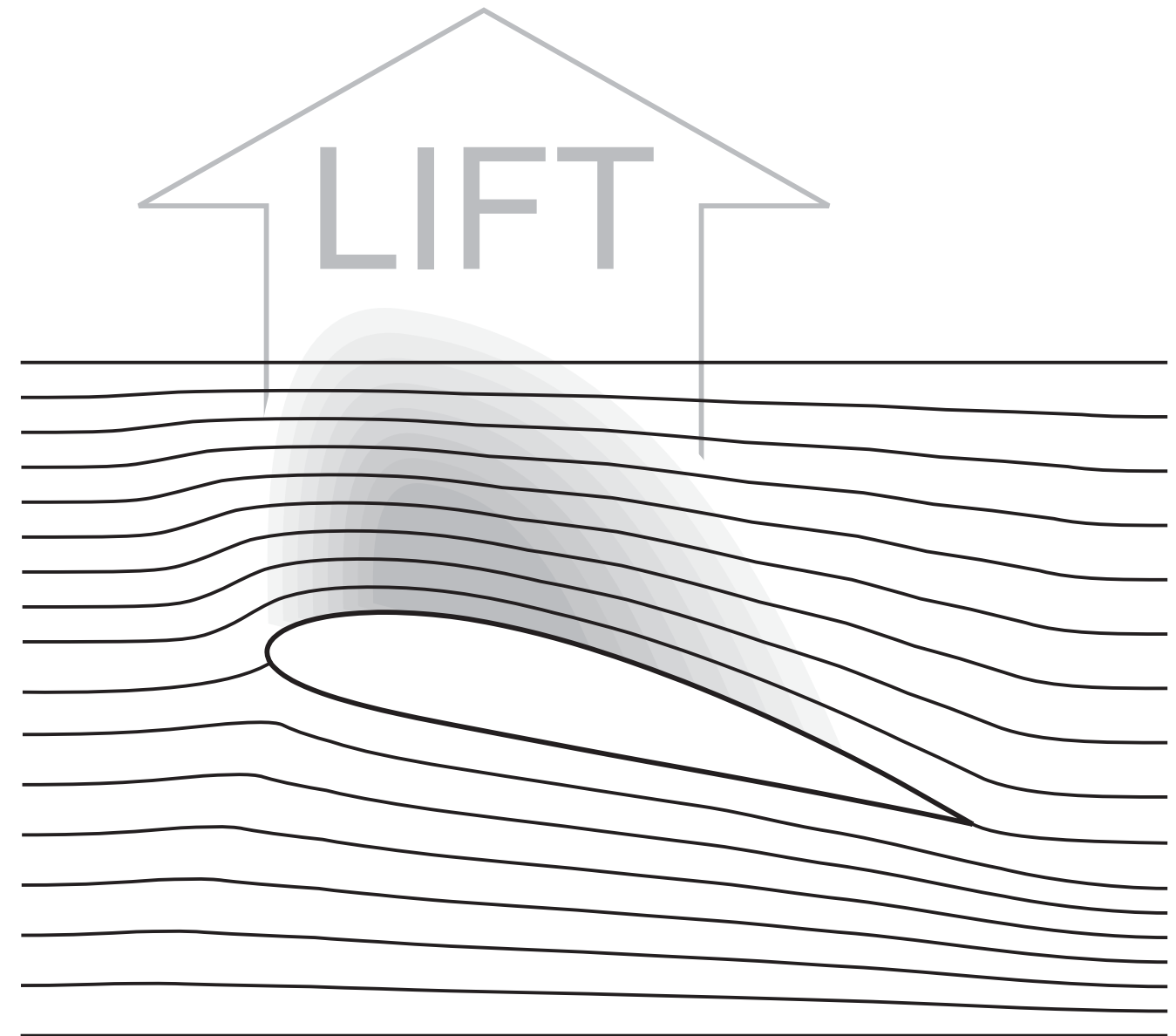
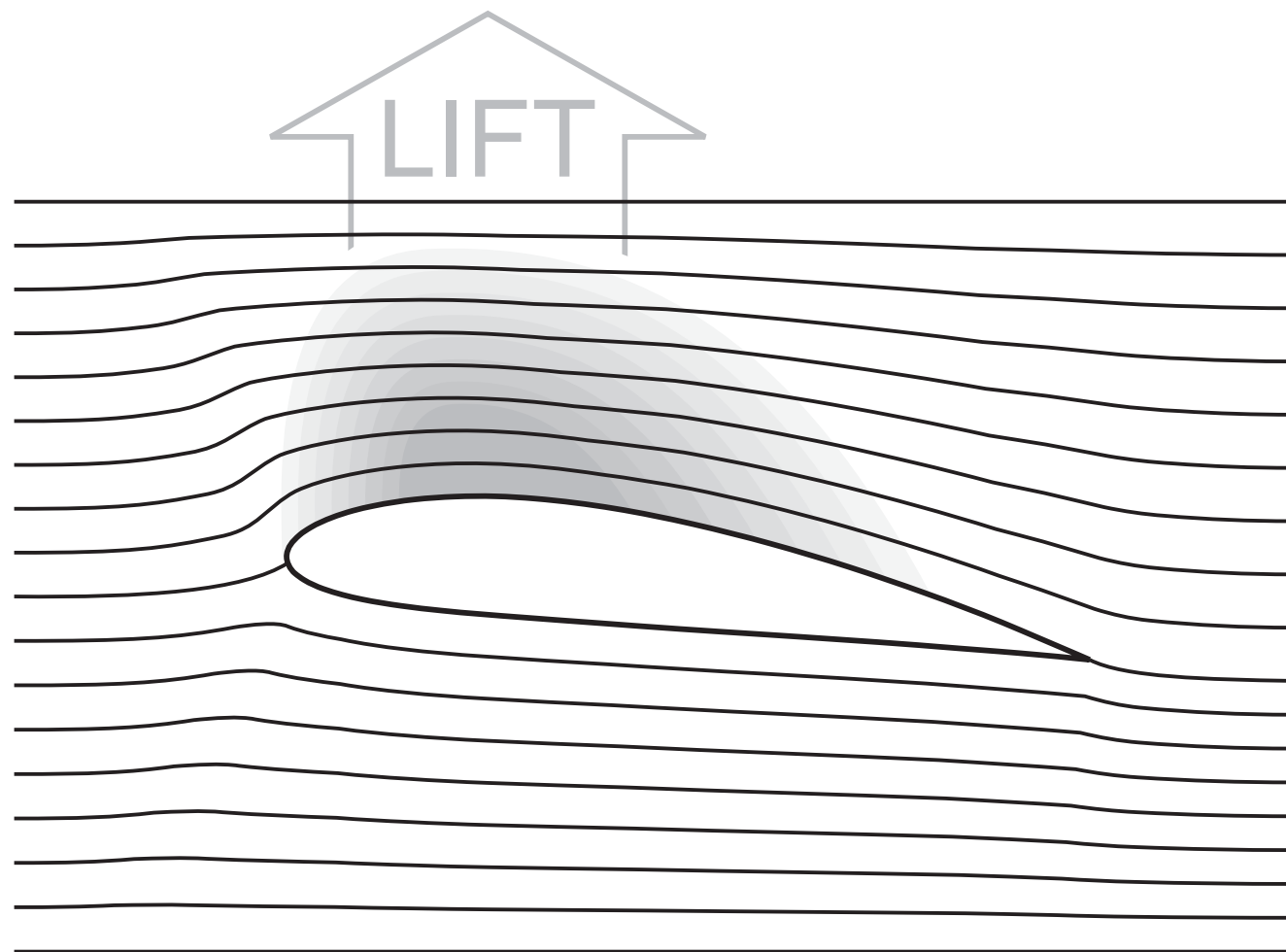
The amount of lift made by a wing is relative to its airspeed as well as its angle of attack. The greater the airspeed, the greater the lift.



Lift and Angle of Attack

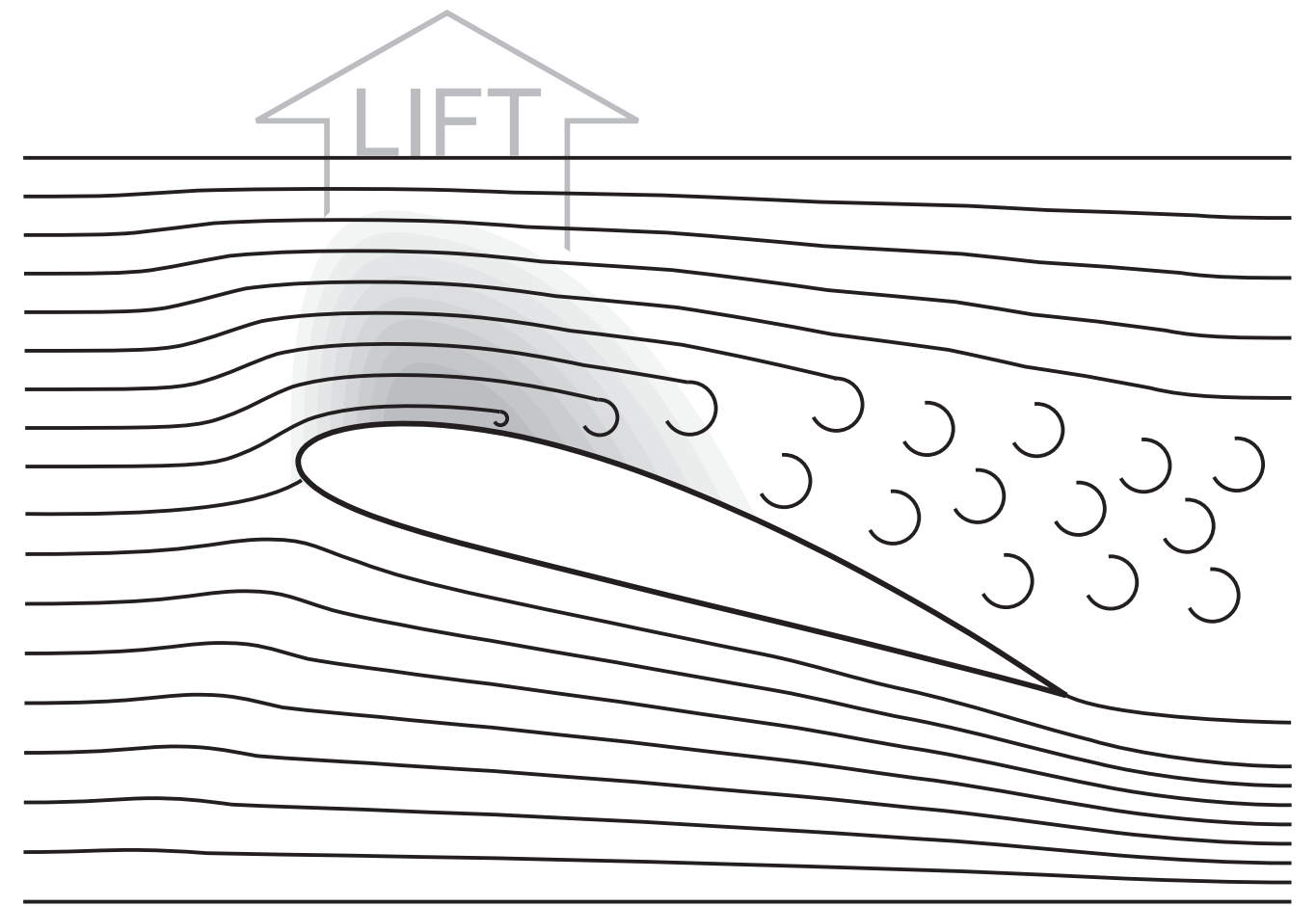
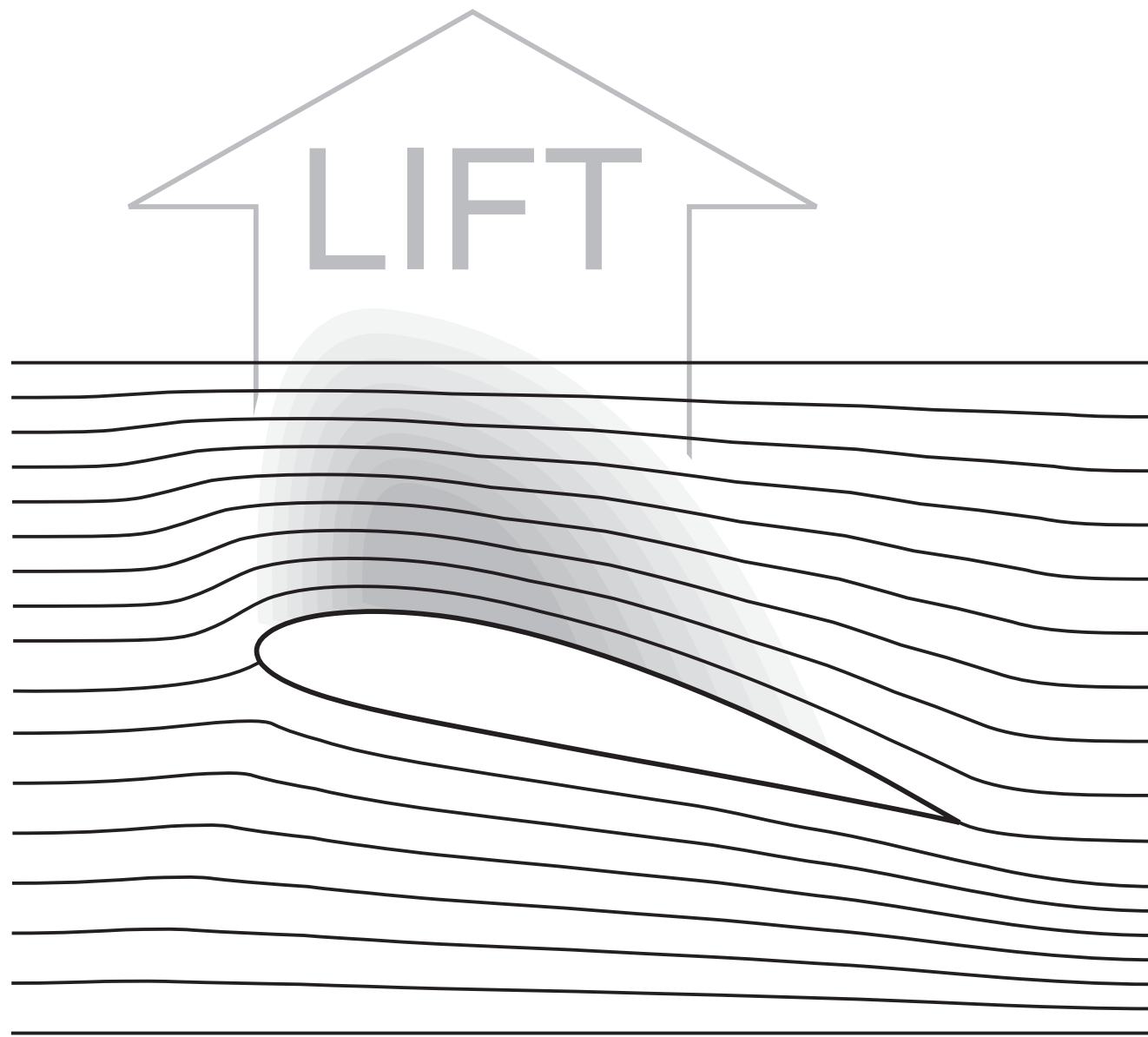
The amount of lift made by a wing is relative to its angle of attack. The steeper the angle of attack, the greater the lift.

But only to a certain degree...



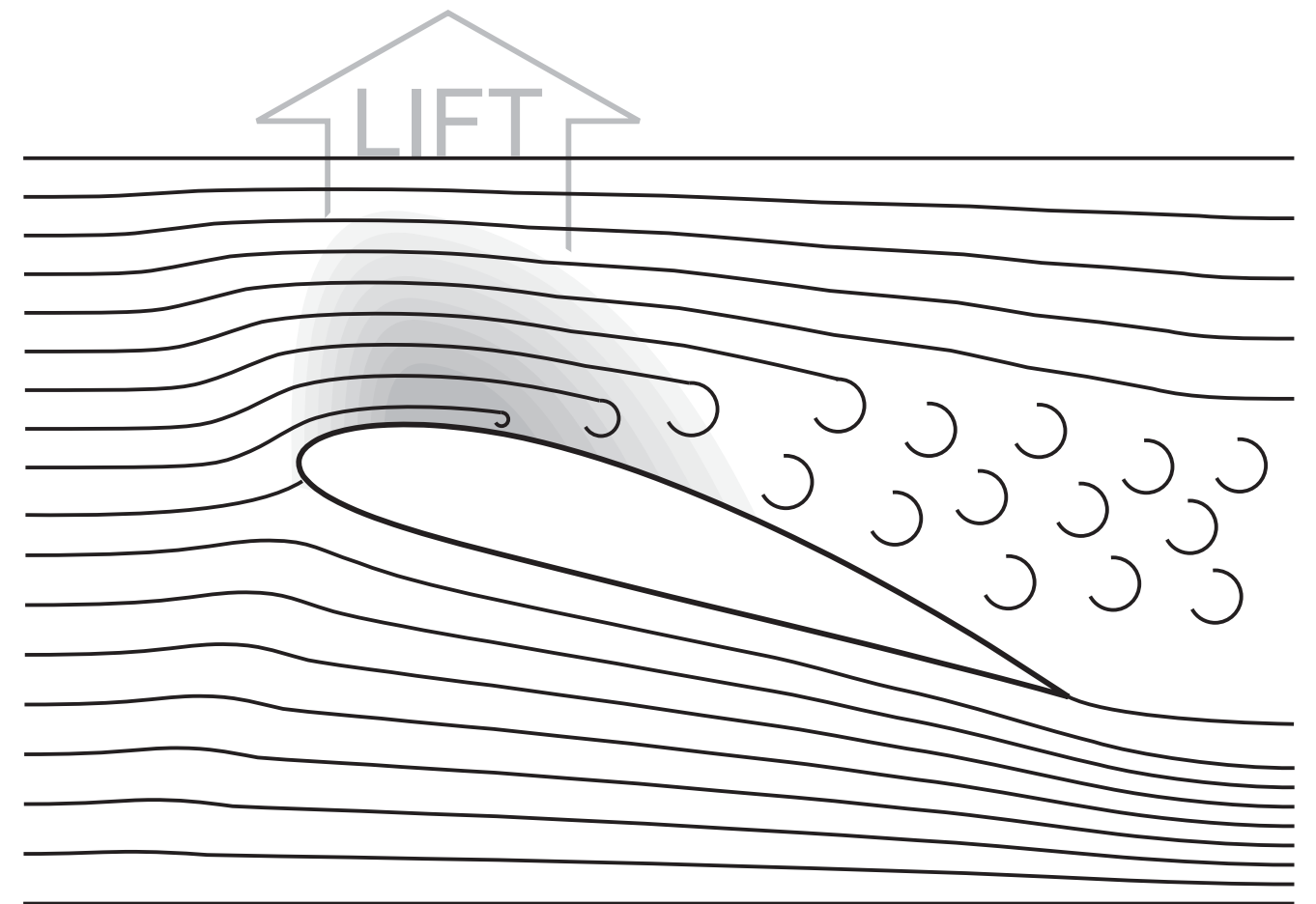
Stall!

Above a certain angle of attack, the air unsticks or "separates" from the top of the wing. Instead of flowing smoothly, it swirls in turbulent eddies like whirlpools in a river.



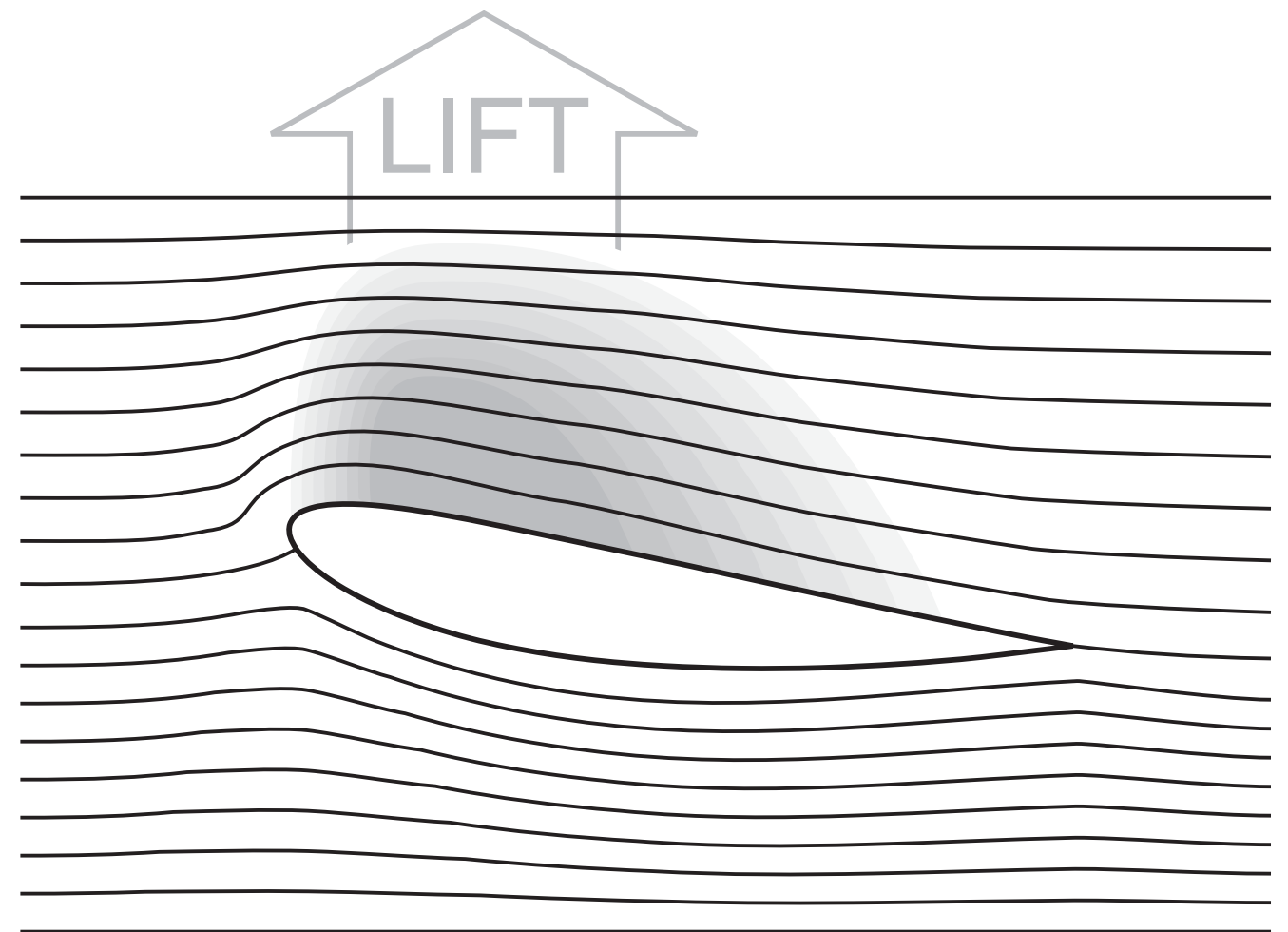
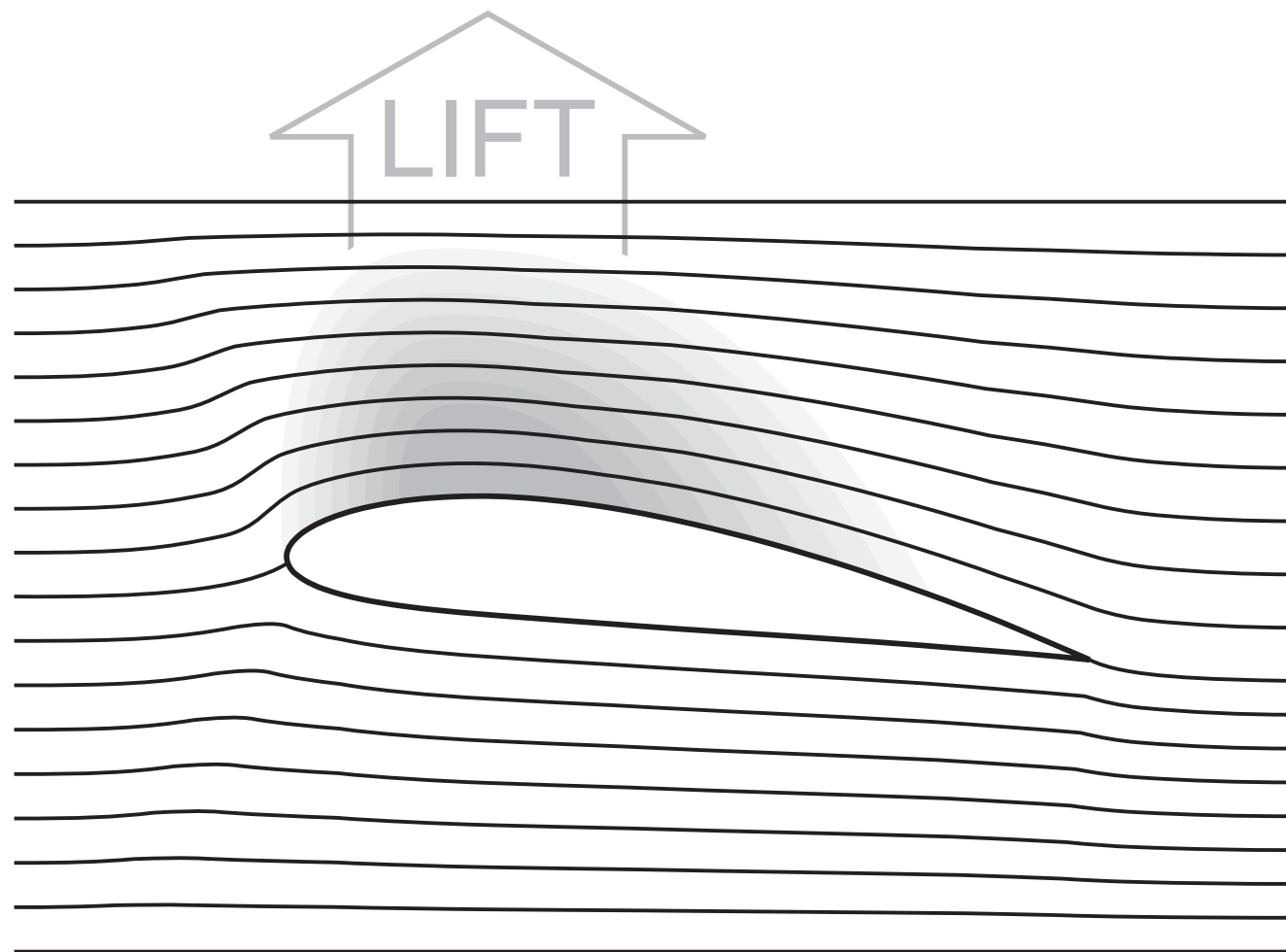
When the air separates from the top of the wing, the pressure difference between the top and bottom of the wing becomes weaker, causing the wing to make much less lift.

The separated flow also produces much more drag than when the air flows smoothly.



Why can airplanes fly upside-down?

You've seen airplanes fly upside-down at airshows and on television. Airfoils work fine upside-down, they're just less efficient, so it takes more power to maintain level flight.

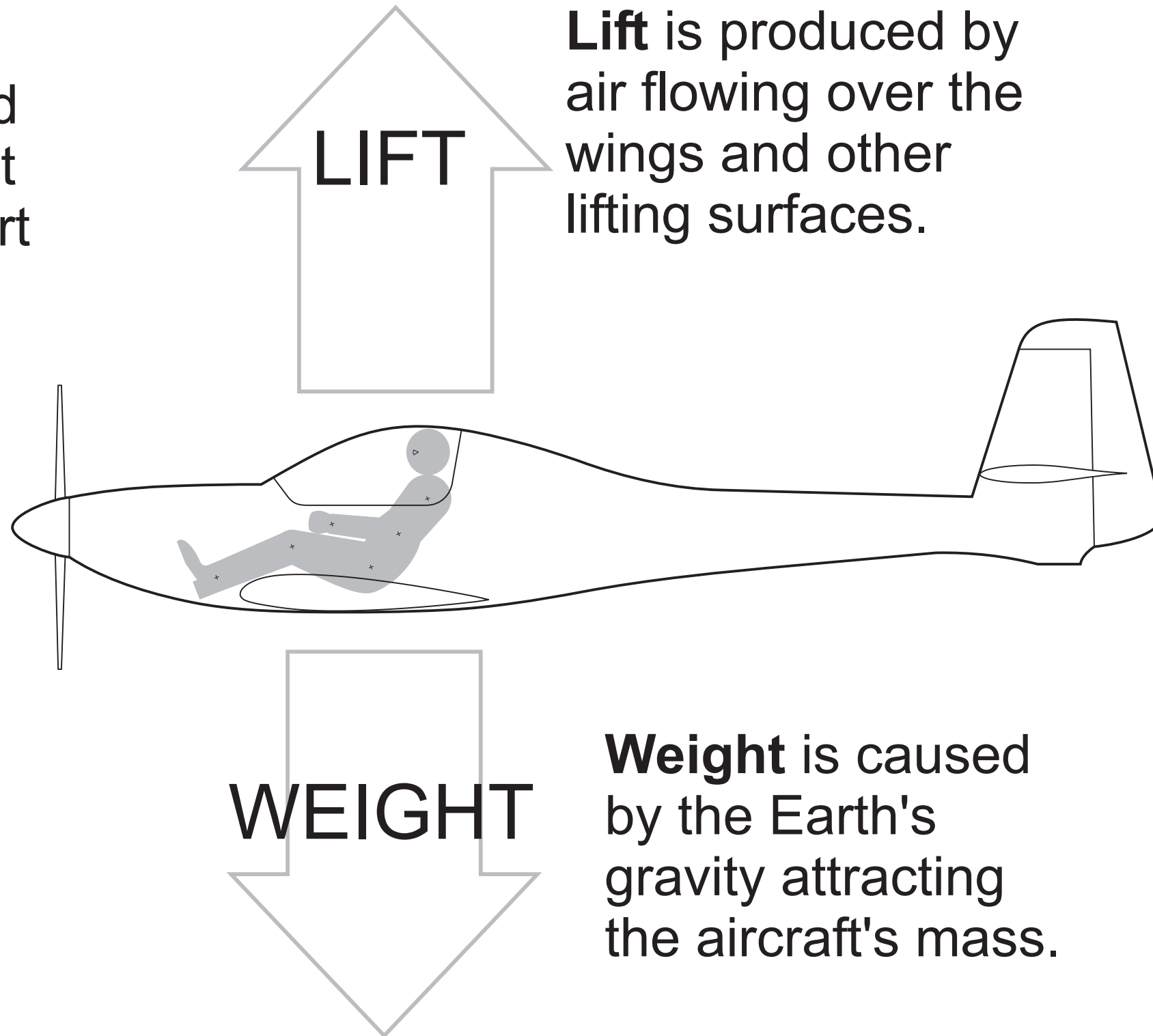


Use the (four) Forces!

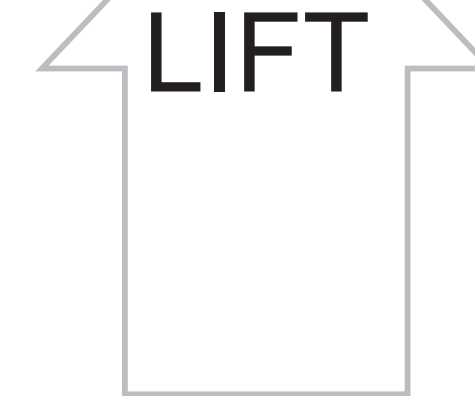
Thrust is created by an engine that accelerates a part of the airflow.



In level flight, **lift** balances **weight** and **thrust** balances **drag**.



Lift is produced by air flowing over the wings and other lifting surfaces.



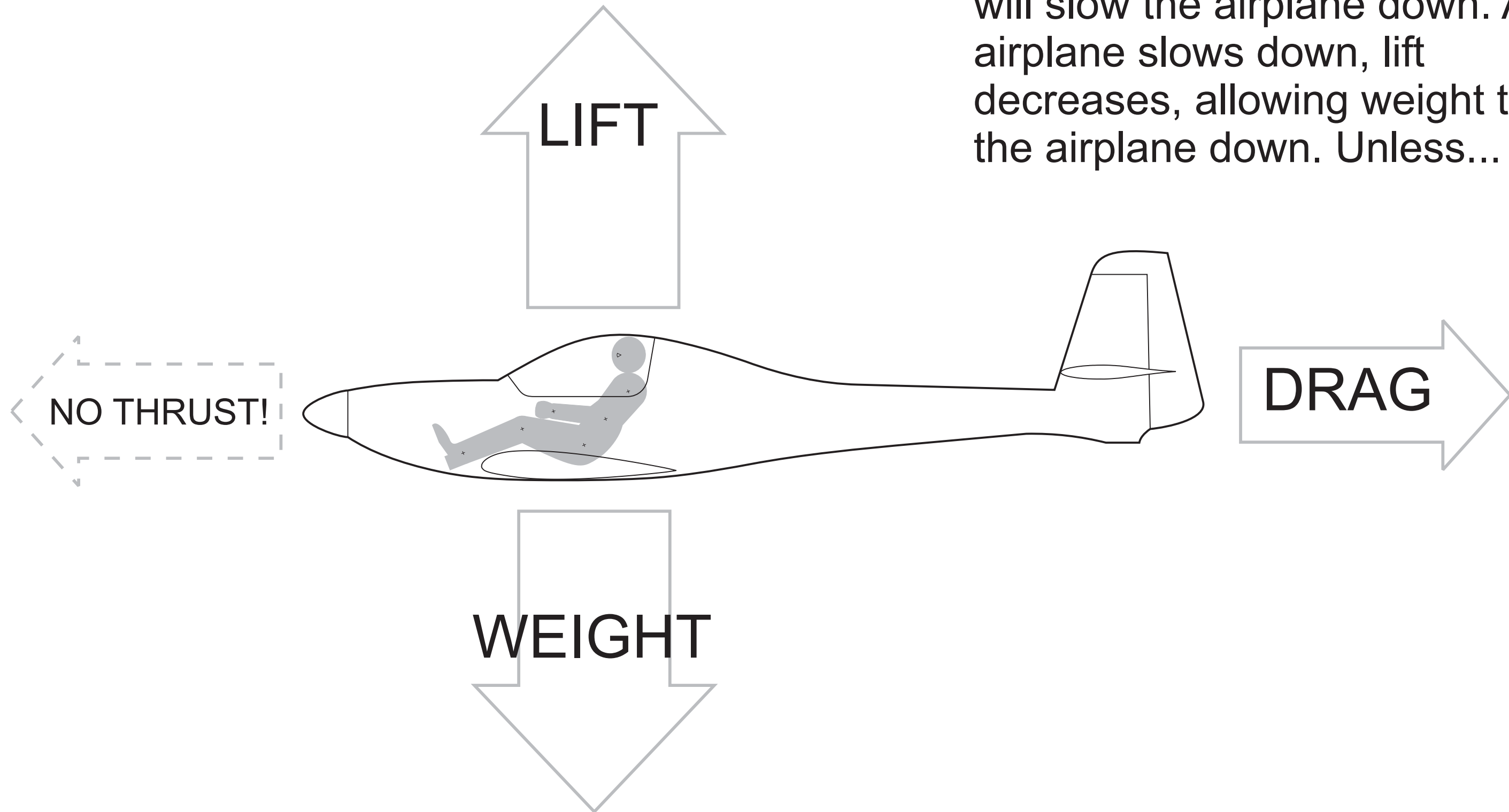
Weight is caused by the Earth's gravity attracting the aircraft's mass.



Drag is caused by air resistance, and also as a byproduct of lift.

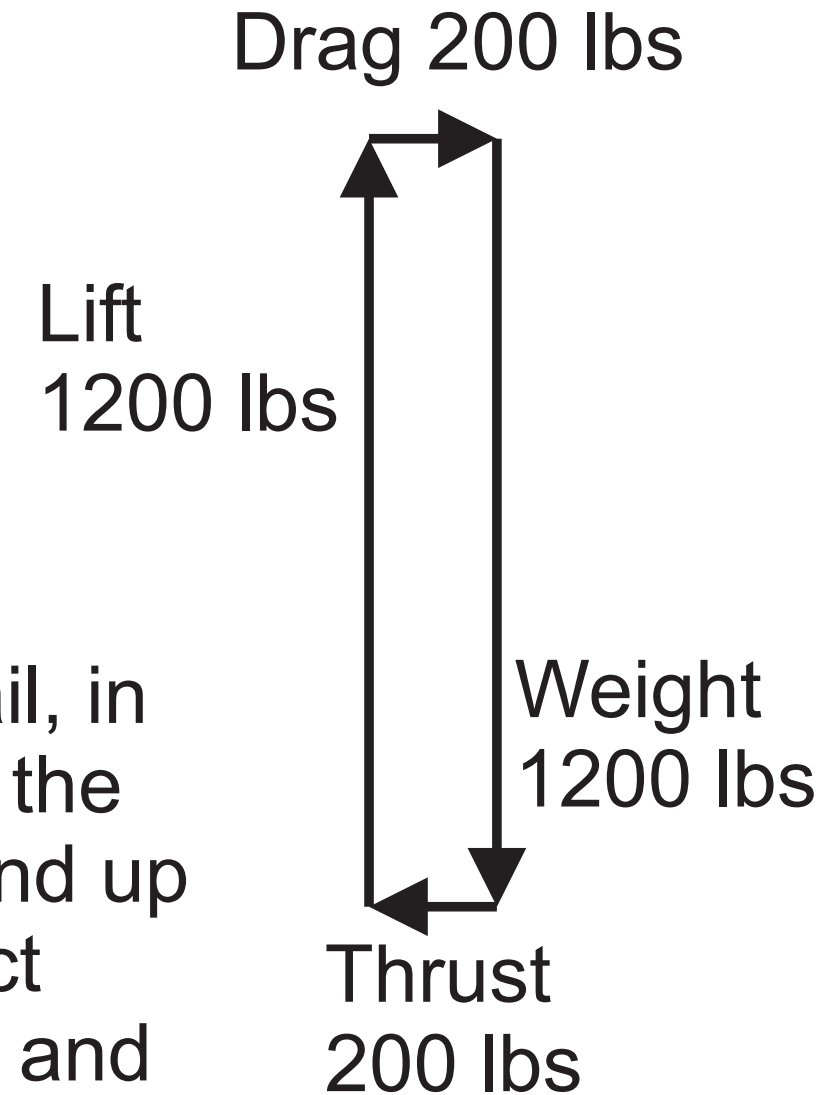
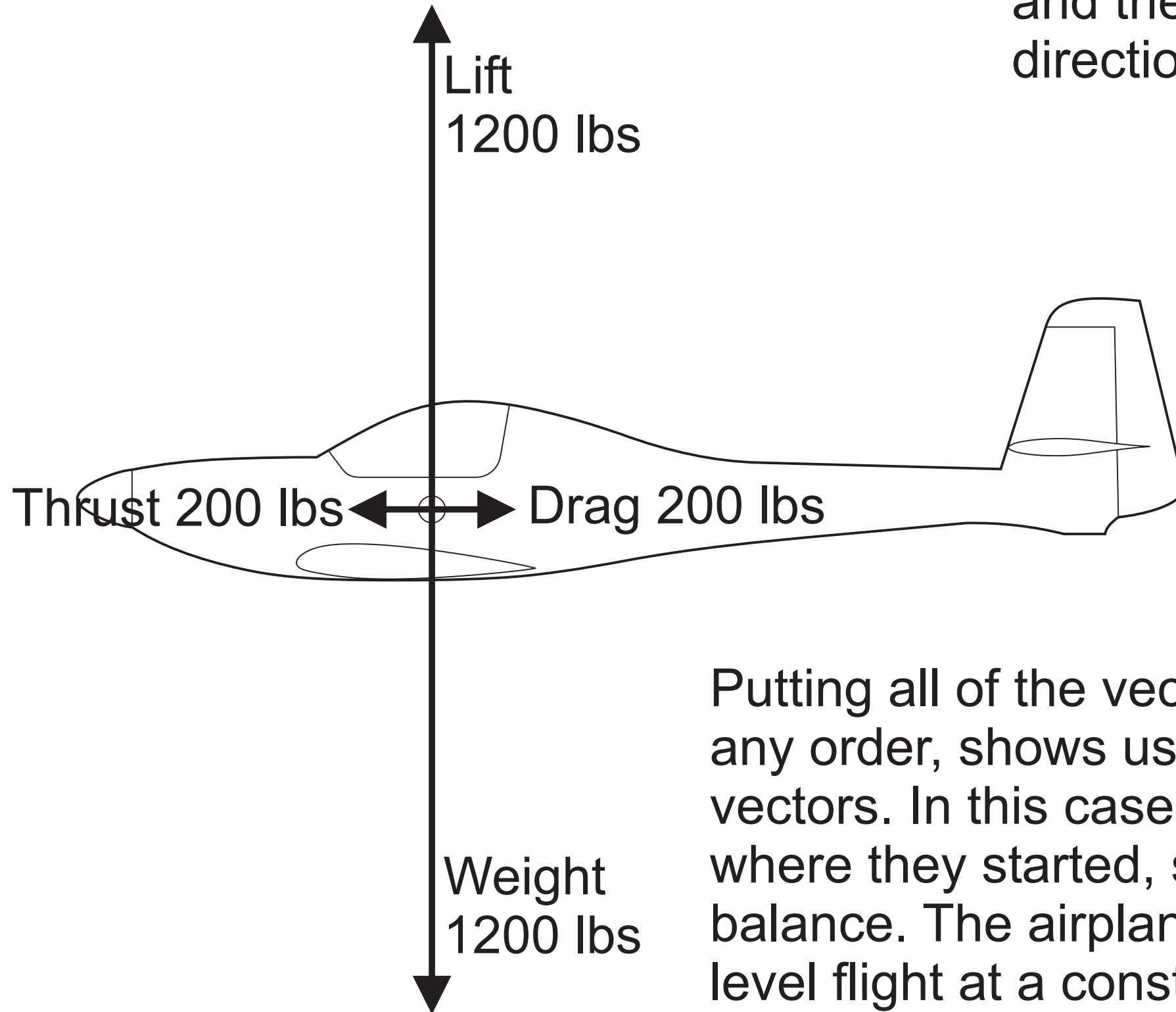
What if the engine quits?

Without the engine's thrust, drag will slow the airplane down. As the airplane slows down, lift decreases, allowing weight to pull the airplane down. Unless...



Let's Use Vectors

We can use vectors to see what forces act on the airplane. We'll draw the vectors as lines of different lengths. The length of the line shows the strength of the force, and the direction of the line shows the direction in which the force acts.

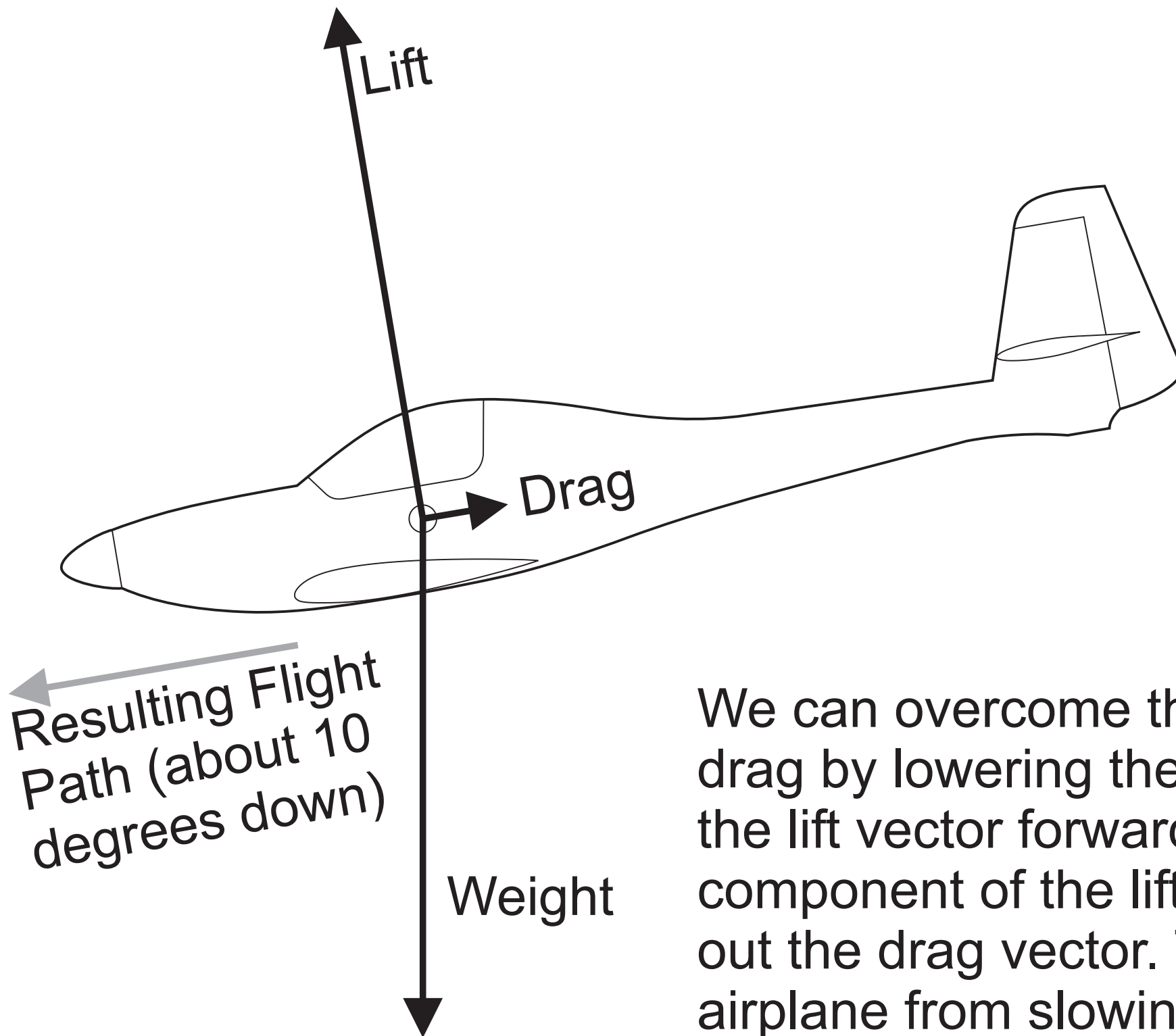


Putting all of the vectors nose to tail, in any order, shows us the sum of all the vectors. In this case, the vectors end up where they started, showing perfect balance. The airplane is in straight and level flight at a constant speed.

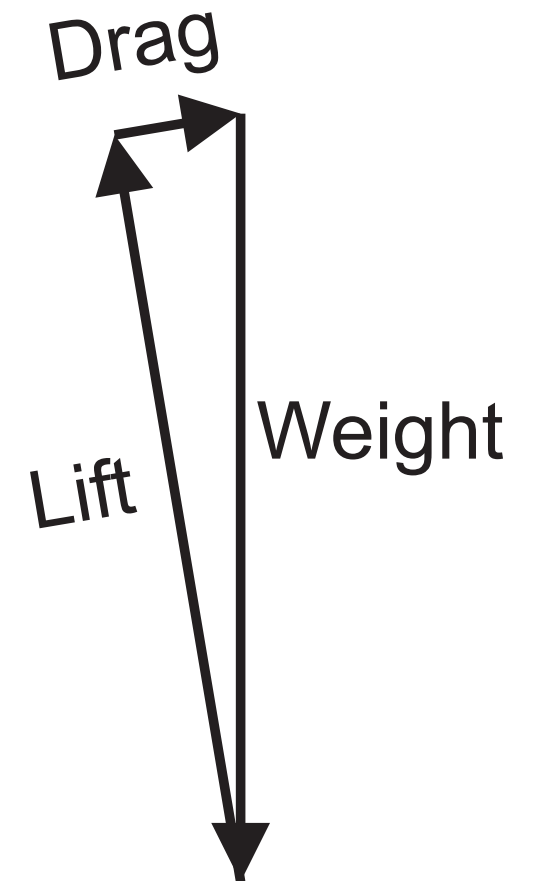
Forces in Gliding Flight

Let's say our airplane weights 1200 lbs and has a lift-to-drag ("L/D") ratio of 6:1 at some speed like 60 m.p.h.

At 60 mph, our airplane produces $1200/6=200$ lbs of drag.



We can overcome the 200 lbs of drag by lowering the nose. That tips the lift vector forward. The forward component of the lift vector balances out the drag vector. That keeps the airplane from slowing down.

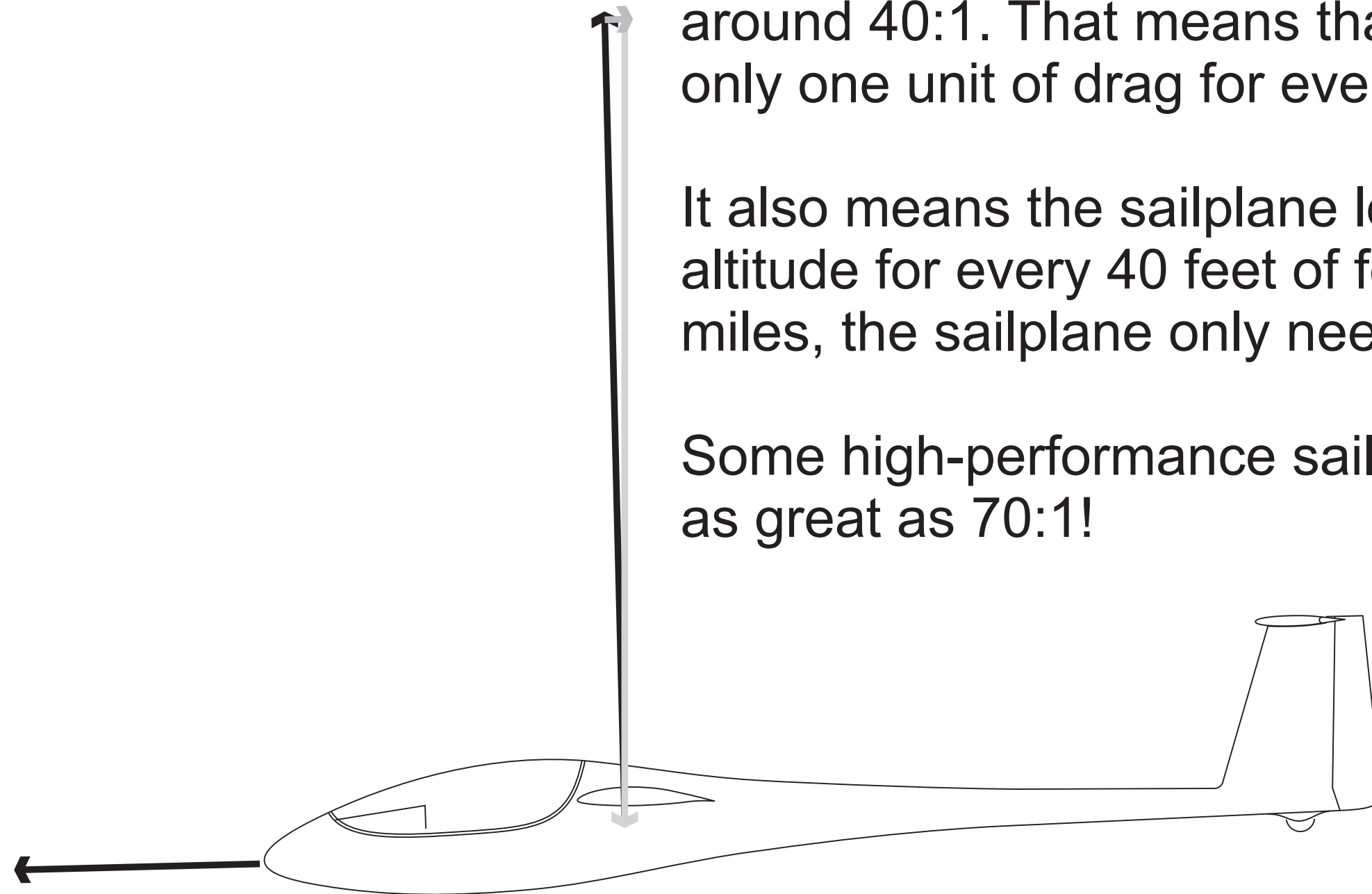


Forces on "Real" gliders (Sailplanes)

Modern sailplanes will typically have best L/D ratios of around 40:1. That means that the sailplane produces only one unit of drag for every 40 units of lift.

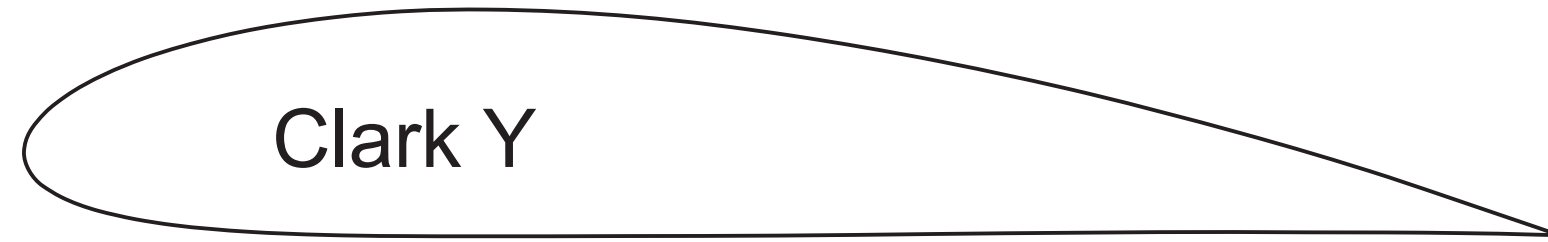
It also means the sailplane loses only one foot of altitude for every 40 feet of forward motion. To go 50 miles, the sailplane only needs 6600 feet of altitude.

Some high-performance sailplanes have best L/D ratios as great as 70:1!



Resulting Flight Path
(Less than 1.5 degrees down)

Evolution of Glider Airfoils



Clark Y

Used in many early gliders and small airplanes. Flat bottom makes it easier to build on top of a table.



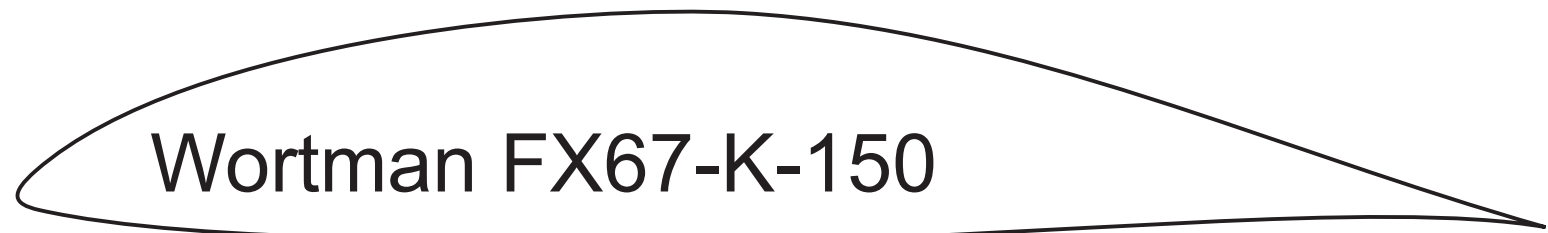
NACA 23012

Developed by NACA (forerunner of NASA) in the 1930s. Still used on many small airplanes, and even some light jets. Has low pitching moment.



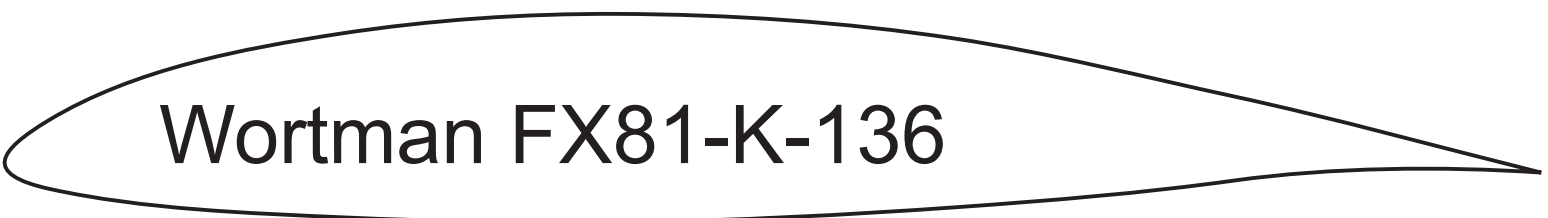
NACA 65₃-618

Developed by NACA in the 1940s. Similar to the airfoil used on the P-51 Mustang. Emphasizes low drag and laminar flow.



Wortman FX67-K-150

Developed by Dr. Felix Wortmann in the 1960s. Achieves extremely low drag and high L/D values, but very sensitive to contamination.



Wortman FX81-K-136

Developed by Dr. Felix Wortmann in the 1980s. Improves on the FX67 series with similar performance over a wider range of conditions.
