The Flight of Birds

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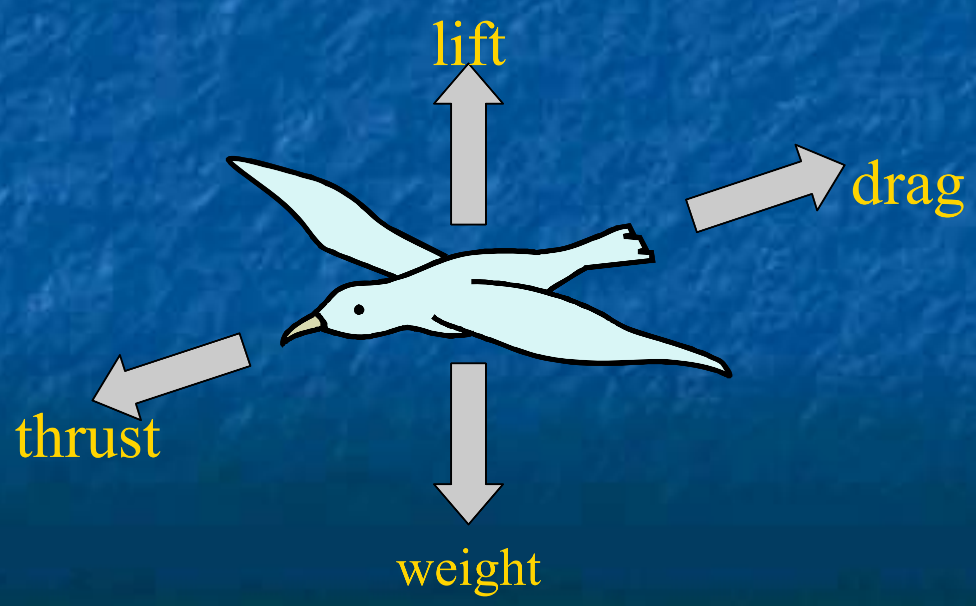
- High speed videos (that give slow motion images) of birds flying can be seen at:

  http://faculty.washington.edu/thedrick

Looking at flight from a physics point of view, there are four main forces that you have to worry about. **Weight** is a force produced by gravity in the downward direction, and every flyer has to produce **lift** in order to counteract weight. Anything moving through air also experiences **drag**, which slows it down, so there must be a forward-moving force, called **thrust**, to oppose the force of drag. These two pairs of forces – weight and lift, drag and thrust – have to be roughly balanced in order for a bird or plane to fly. In this exhibit, we'll be primarily concerned with lift.



How Is Lift Generated?

Do you find it incredible that an object (bird or plane) can fly? In order for something to fly, it needs to generate enough lift to counteract its own weight. How a bird or plane creates this lift can be explained by the Bernoulli effect.

Bird wings are shaped so that the distance from the front to the back over the top of the wing is greater than the distance under the wing. Yet, the same amount of air must flow over both the top of the wing and the bottom. In order for the same amount of air to pass over the longer distance on top, the air on top must move faster than it does over the bottom of the wing. The air over the wing is at a lower pressure. This occurrence is termed the Bernoulli effect. If a bird is moving fast enough, the force from the pressure difference, which is called the lift force, equals or exceeds the weight of the bird and the bird is able to fly.

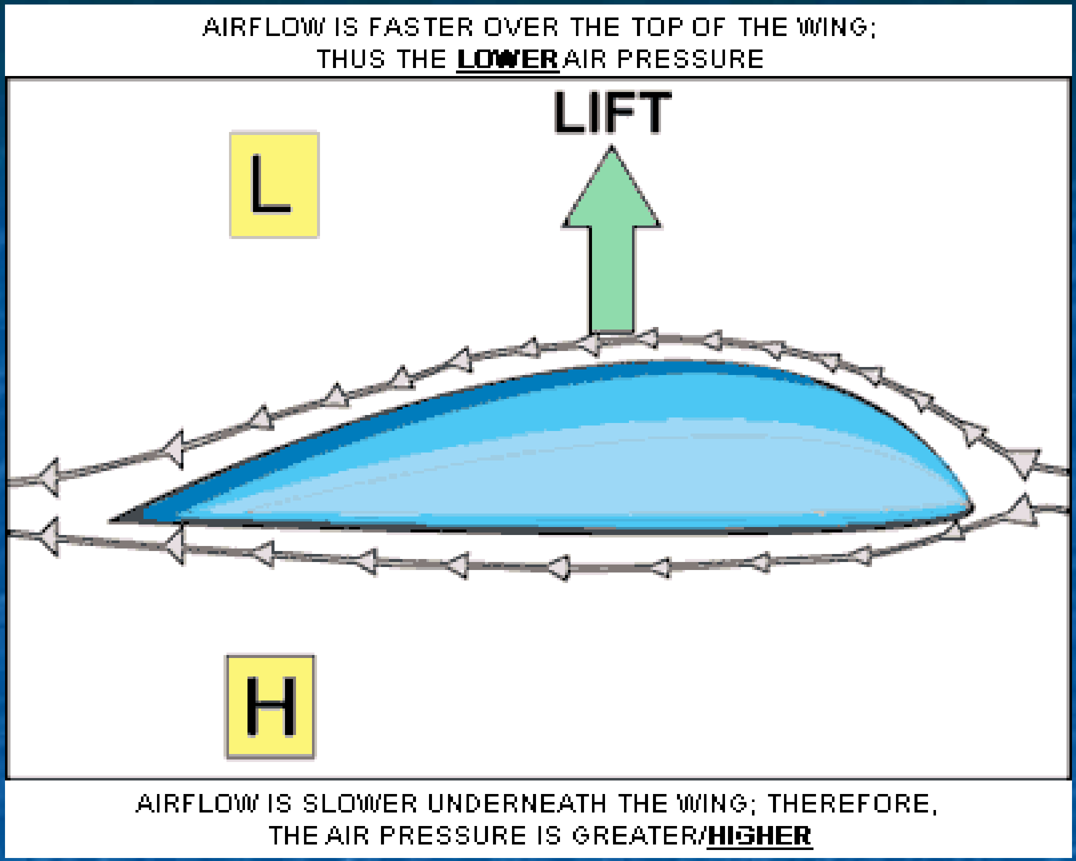


Image courtesy of NASA.

When air flows over an airfoil, the air flows faster over the top of the wing and slower under the wing. The faster flowing air exerts a lower pressure than the slower moving air. The pressure difference causes an upward force called lift, which enables the bird to fly.

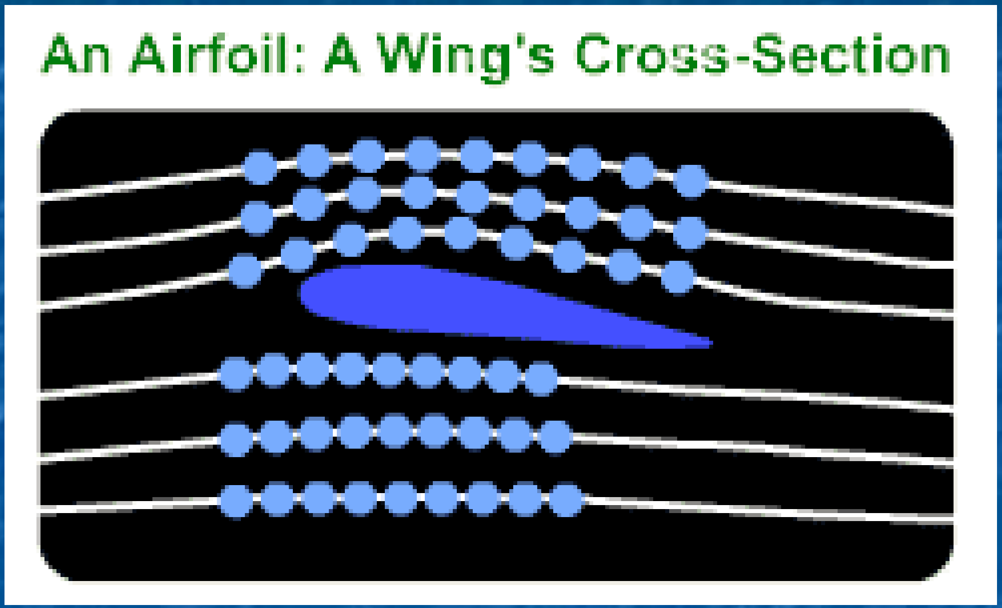


Image courtesy of NASA.

Air flowing around an object must travel a longer distance in the same amount of time that it would take to travel in a straight path. So, the air flowing around the object must travel faster.

What Factors Affect Lift?

When looking at the amount of lift that a pair of wings can produce (and hence amount of weight that they can support), a few factors come into play: wing size, airspeed, air density, and the angle of the wings with respect to the direction of flight (called angle of attack).

Wing Size

The relationship between wing size and lift is pretty simple. A wing’s **lift** ***L*** is directly proportional to the **surface area** ***S*** of the wing. So, a wing twice as large can carry twice as much weight.

Airspeed

The relationship between lift and airspeed, however, is less straightforward. The mass flow of air around a wing is proportional to the **airspeed *V*** times the **air density *d***. According to Newton's Second Law of Motion, the force produced by the air flowing around the wings is proportional to the airspeed times the mass flow of air—VdV, which can also be written as dV^2.

What this means practically is that if a bird flies twice as fast, it generates 4 times as much lift. Also, if a plane flies at a high altitude of 39,000 feet, where the air density is a quarter of the air density at sea level, then it must fly twice as fast to maintain the same amount of lift.

Airspeed

You can see how airspeed produces lift in the demonstration with the long, thin tube.

- Hold the tube upright so that the clamp is against the floor.
- Place the ping pong ball at the bottom of the tube.
- Hold the leaf blower so that it blows air horizontally across the top of the tube.
- As the airspeed increases, the pressure in the tube decreases, lifting the ping pong ball up off the floor.

Angle of Attack

The final factor is the **angle of attack**, which is the angle between the wing and the direction of the oncoming wind.

Experiment with the demonstration with the airfoil to help understand the relation between lift and angle of attack. Rotate the peg attached to the wing to adjust the angle. As you slowly rotate the peg clockwise, you bring the leading (front) edge of the wing up, increasing the angle of attack and the amount of lift generated. At small angles of attack, the threads, showing the air flow, stay close to the wing. At higher angles of attack, the threads, and the air flow, separate from the wing. As this happens, the air moving over the wing stops flowing smoothly, causing a large loss in lift. For a large bird, this critical angle is about 20°. Birds can adjust the angle of attack of their wings to suit circumstances, but for long distance flights, they hold their wings at an angle of attack of 6°.

Lift increases as angle of attack increases, but only up until a certain critical angle. At that point, stall occurs as the air stops flowing smoothly over the top surface and instead peels away, leaving a turbulent wake.

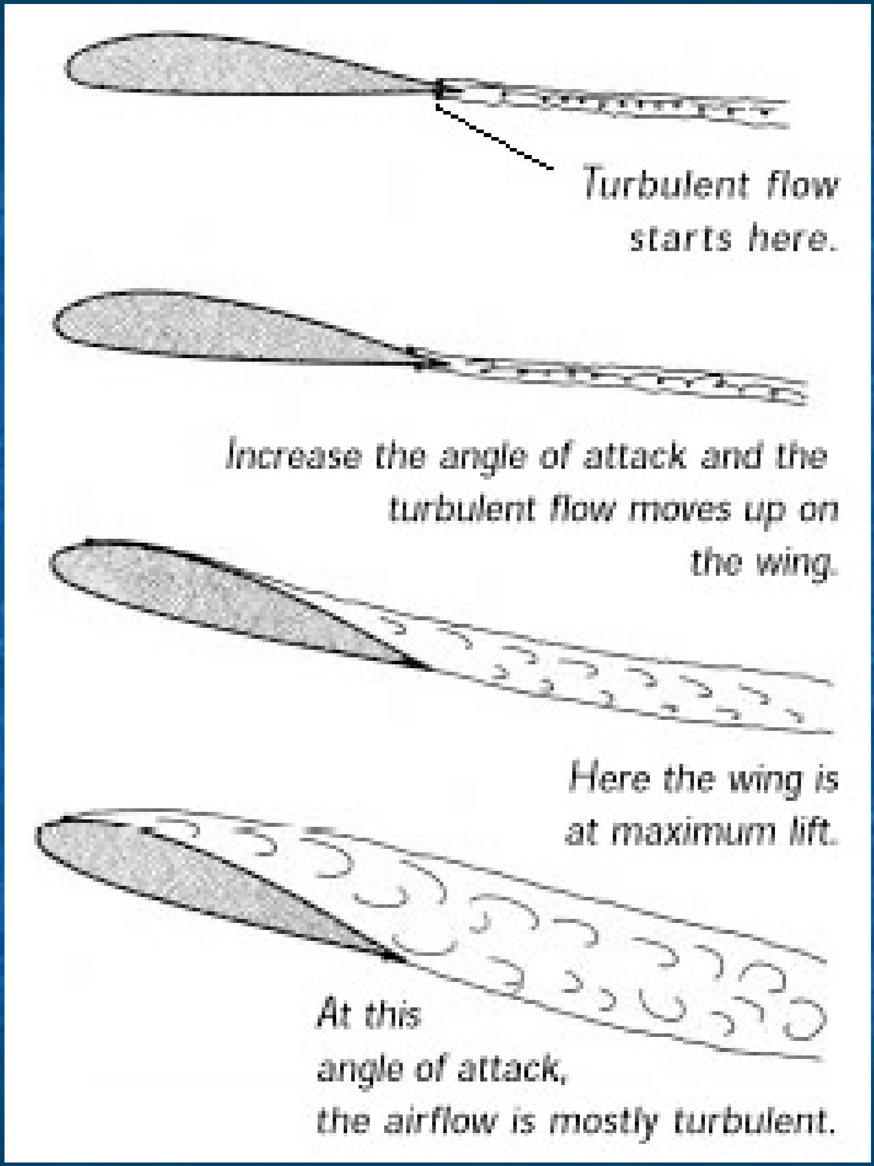


Image courtesy of NASA.

Putting it all together…

Since a bird's wings have to support its weight against the force of gravity, lift must equal the weight *W*, and since lift is related to the surface area of a wing *S* and to dV^2:

$$W = 0.3dV^2S$$

(The 0.3 is a constant related to the angle of attack for long-distance flight: its average value is 6° for birds.)

This equation can also be simplified and rearranged by setting d, the density of air at sea level, to be 1.25 kilograms per cubic meter. Since birds fly relatively close to sea level, it is safe to use this number in the equation. We can also divide both sides by the wing area *S*, leading to the new equation:

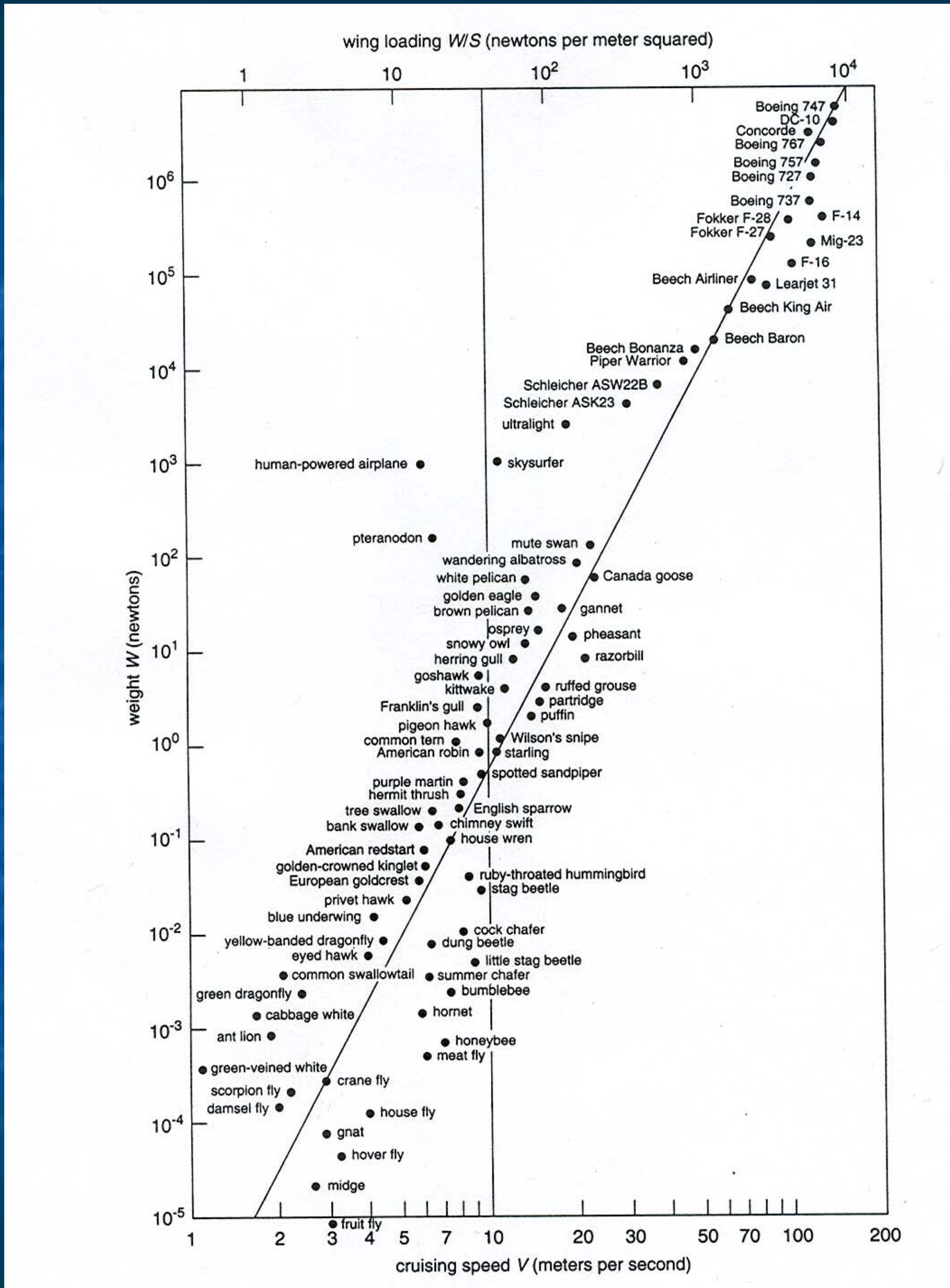
$$\frac{W}{S} = 0.38V^{2}$$

W/S is the amount of weight supported by a wing divided by the surface area of the wing. This is called a bird's "**wing loading**," and the great a bird's wing loading, the faster it must fly.

Weight, Wing Area, Wing Loading, and Airspeeds for Various Seabirds

				V	
	W (Newtons)	S (square meters)	W/S	m/sec	mph
Common tern	1.15	0.050	23	7.8	18
Black-headed gull	2.30	0.075	31	9.0	20
Common gull	3.67	0.115	32	9.2	21
Royal tern	4.70	0.108	44	10.7	24
Herring gull	9.40	0.181	52	11.7	26
Great skua	13.5	0.214	63	12.9	29
Great black-backed gull	19.2	.272	71	13.6	31
Sooty albatross	28.0	0.340	82	14.7	33
Wandering albatross	87.0	0.620	140	19.2	43

Table adapted from Tennekes, Henk. *The Simple Science of Flight*. Cambridge, MA: MIT Press, 1997.



This graph shows the proportional relationship between weight and wing loading for various species of birds and types of aircraft. The vertical line marks a cruising speed of 10 meters/second (22mph) and the diagonal line is a reference "trend line". Birds and aircraft that lie on or very close to this line fit the standard form, with ordinary wings and middle-of-the-road wing loading. Flyers that lie off the line usually have special design requirements. Notice that the graph includes insects (the house fly), birds (e.g. the sparrow) and airplanes (e.g. Boeing 737). All follow the same physics of flight.

Image taken from Tennekes, Henk. *The Simple Science of Flight*. Cambridge, MA: MIT Press, 1997.