Background

How is it that today's airplanes, some of which have a maximum take off weight of a million pounds or more, are able to get off the ground in the first place, let alone fly between continents? Surprisingly, even with today's technological advances, we still use the same principles of aerodynamics used by the Wright brothers in 1903. In order to gain an understanding of flight, it is important to understand the forces of flight (lift, weight, drag, and thrust), the Bernoulli Principle, and Newton's first and third laws of motion. Although the activities in this lesson primarily focus on the role the Bernoulli Principle plays in the ability of aircraft to achieve lift, the Bernoulli Principle is not the only reason for flight.

The Forces of Flight

At any given time, there are four forces acting upon an aircraft. These forces are lift, weight, drag and thrust. Lift is the key aerodynamic force that keeps objects in the air. It is the force that opposes weight and thus, the force that helps keep an aircraft in the air. Weight is the force that works vertically by pulling all objects, including aircraft, toward the center of the Earth. In order to fly, an aircraft needs something to press it in the opposite direction of gravity, and the weight of an object controls how strong that pressure will need to be. Lift is that pressure. Drag is a mechanical force generated by the interaction and contract of a solid body, such as an airplane, with a fluid (liquid or gas). Finally there is thrust, or the force that is generated by the engines of an aircraft in order to move the aircraft forward in its path.

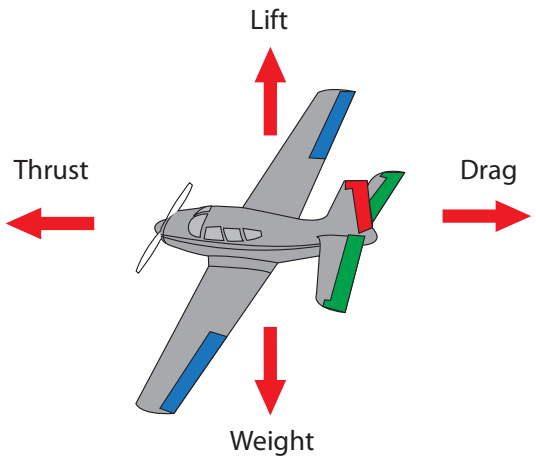
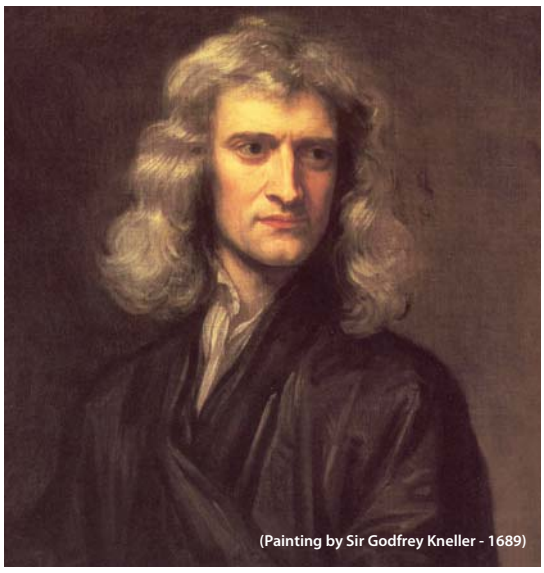


Fig. 1 Four forces of flight

Newton's Laws of Motion

Also, essential to an understanding of how airplanes fly, are the laws of motion first described by Sir Isaac Newton. Newton (1642 -1727) was an English physicist, mathematician, astronomer, alchemist, theologian and natural philosopher. He has long been considered one of the most influential men in human history. In 1687, Newton published the book "Philosophiae Naturalis Principia Mathematica", commonly known as the "Principia". In "Principia" , Newton explained the three laws of motion. Newton's first and third laws of motion are especially helpful in explaining the phenomenon of flight. The first law states that an object at rest remains at rest while an object in motion remains in motion, unless acted upon by an external force. Newton's second law states that force is equal to the change in momentum per change in time. For constant mass, force equals mass times acceleration or F=m·a. Newton's third law states that for every action, there is an equal and opposite reaction.



Img. 1 Sir Isaac Newton (age 46)

The Bernoulli Principle

So, how does Daniel Bernoulli, who is known for the Bernoulli Principle, figure into all of this? Bernoulli built his work off of that of Newton.

Img. 2 Daniel Bernoulli

Bernoulli (1700 – 1782) was a Dutch-born scientist who studied in Italy and eventually settled in Switzerland. Daniel Bernoulli was born into a family of renowned mathematicians. His father, Johann Bernoulli, was one of the early developers of calculus and his uncle Jacob Bernoulli, was the first to discover the theory of probability. Although brilliant, Johann Bernoulli was both ambitious for his son Daniel and jealous of his son's success. Johann insisted that Daniel study business and later medicine, which Daniel did with distinction. It was mathematics, however, that really captured Daniel's interest and imagination. Despite Daniel's best efforts, Johann never acknowledged his son's brilliance and even tried to take credit for some of Daniel's most important ideas.

After Daniel's studies, he moved to Venice where he worked on mathematics and practical medicine. In 1724, he published Mathematical exercises, and in 1725 he designed an hourglass that won him the prize of the Paris Academy, his first of ten. As a result of his growing fame as a mathematician, Daniel was invited to St. Petersburg to continue his research. Although Daniel was not happy in St. Petersburg, it was there that he wrote "Hydrodynamica", the work for which he is best known.

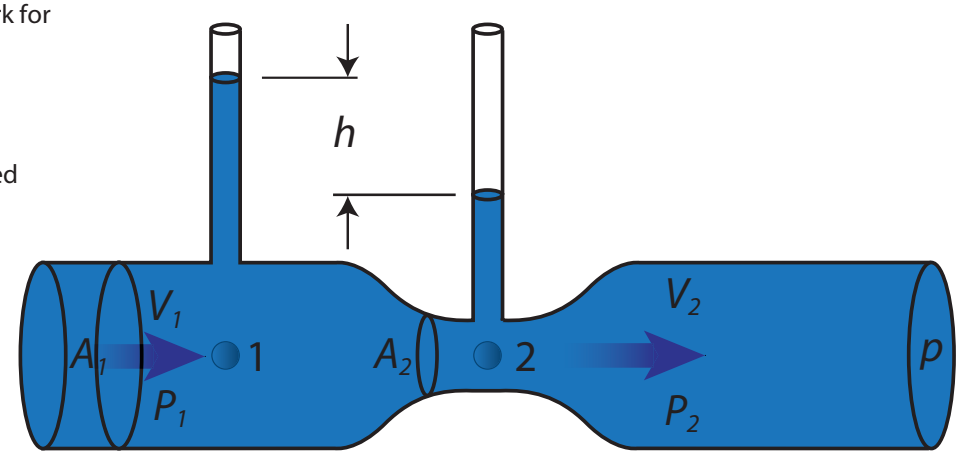


Fig. 2 Bernoulli fluid experiment

In 1738, Bernoulli published "Hydrodynamica", his study in fluid dynamics, or the study of how fluids behave when they're in motion. Air, like water, is a fluid; however, unlike water, which is a liquid, air is a gaseous substance. Air is considered a fluid because it flows and can take on different shapes. Bernoulli asserted in "Hydrodynamica" that as a fluid moves faster, it produces less pressure, and conversely, slower moving fluids produce greater pressure.

By gaining an understanding of the forces at work on an airplane and what principles guide those forces, we are able to explain how lift is generated for an airplane. First, it takes a force, or thrust, to get the airplane moving. That's Newton's first law at work. This law states that an object at rest remains at rest while an object in motion remains in motion, unless acted upon by an external force.

Then because of the shape of an airplane's wing, called an airfoil, the air into which the airplane flies is split at the wing's leading edge, passing above and below the wing at different speeds so that the air will reach the same endpoint along the trailing edge of the wing at the same time. In general, the wing's upper surface is curved so that the air rushing over the top of the wing speeds up and stretches out, which decreases the air pressure above the wing. In contrast, the air flowing below the wing moves in a straighter line, thus its speed and pressure remain about the same. Since high pressure always moves toward low pressure, the air below the wing pushes upward toward the air above the wing. The wing, in the middle, is then "lifted" by the force of the air perpendicular to the wing. The faster an airplane moves, the more lift there is. When the force of lift is greater than the force of gravity, the airplane is able to fly, and because of thrust, the airplane is able to move forward in flight. According to Newton's third law of motion, the action of the wings moving through the air creates lift.

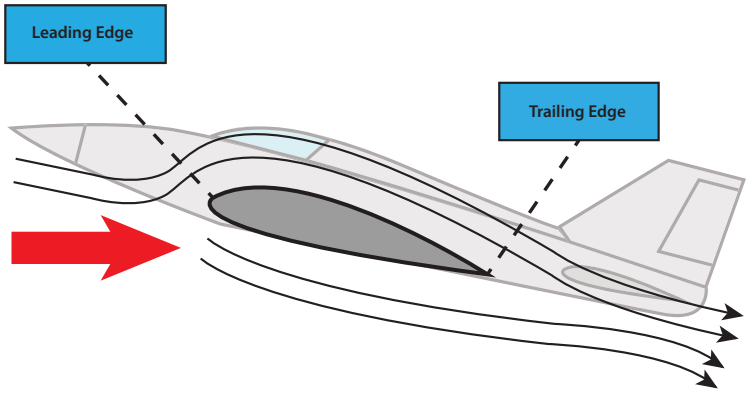


Fig. 3 Airfoil