

Four forces on an airplane

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TOP: An airplane pictured on June 30, 2016. Courtesy of Pexels. BOTTOM: Four forces on an airplane. Courtesy of NASA.

A force may be thought of as a push or pull in a specific direction. A force is a vector quantity, so a force has both a magnitude and a direction. When describing forces, we have to specify both the magnitude and the direction. This slide shows the forces that act on an airplane in flight.

Weight

Weight is a force that is always directed toward the center of the earth. The magnitude of the weight depends on the mass of all the airplane parts, plus the amount of fuel, plus any payload on board (people, baggage, freight, etc.). The weight is distributed throughout the airplane. But we can often think of it as collected and acting through a single point called the center of gravity. In flight, the airplane rotates about the center of gravity.

Flying encompasses two major problems: overcoming the weight of an object by some opposing force, and controlling the object in flight. Both of these problems are related to the object's weight and the location of the center of gravity. During a flight, an airplane's weight

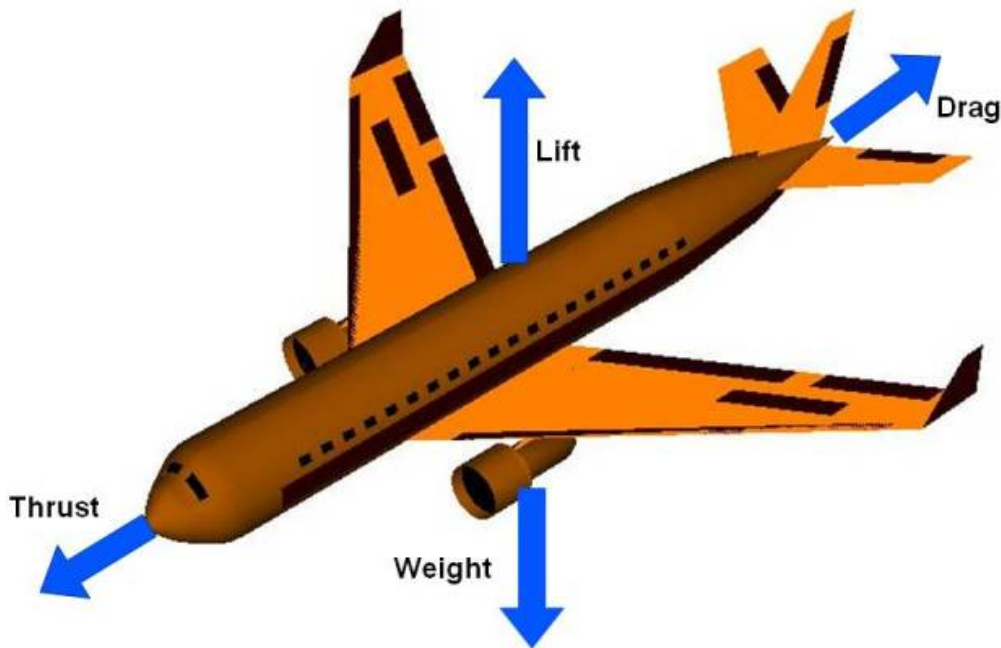
constantly changes as the aircraft consumes fuel. The distribution of the weight and the center of gravity also changes. So the pilot must constantly adjust the controls to keep the airplane balanced, or trimmed.

Lift

National Aeronautics and Space Administration



Four Forces on an Airplane



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Airplanes generate an opposing force called lift to overcome the weight force. Lift is generated by the motion of the airplane through the air and is an aerodynamic force. "Aero" stands for the air, and "dynamic" denotes motion. Lift is directed perpendicular to the flight direction. The magnitude of the lift depends on several factors including the shape, size and velocity of the aircraft. As with weight, each part of the aircraft contributes to the aircraft lift force. Most of the lift is generated by the wings. Aircraft lift acts through a single point called the center of pressure. The center of pressure is defined just like the center of gravity, but using the pressure distribution around the body instead of the weight distribution.

The distribution of lift around the aircraft is important for solving the control problem. Aerodynamic surfaces are used to control the aircraft in roll, pitch and yaw.

Drag

As the airplane moves through the air, there is another aerodynamic force present. The air resists the motion of the aircraft and the resistance force is called drag. Drag is directed along and opposed to the flight direction. Like lift, there are many factors that affect the magnitude of the drag force, including the shape of the aircraft, the "stickiness" of the air and the velocity of the aircraft. Like lift, we collect all of the individual components' drags and combine them into a single aircraft drag magnitude. And like lift, drag acts through the aircraft center of pressure.

Thrust

To overcome drag, airplanes use a propulsion system to generate a force called thrust. The direction of the thrust force depends on how the engines are attached to the aircraft. In the figure shown above, two turbine engines are located under the wings, parallel to the body, with thrust acting along the body centerline. On some aircraft, such as the Harrier, the thrust direction can be varied to help the airplane take off in a very short distance. The magnitude of the thrust depends on many factors associated with the propulsion system, including the type of engine, the number of engines and the throttle setting.

For jet engines, it is often confusing to remember that aircraft thrust is a reaction to the hot gas rushing out of the nozzle. The hot gas goes out the back, but the thrust pushes toward the front. Action <--> reaction is explained by Newton's Third Law of Motion.

The motion of the airplane through the air depends on the relative strength and direction of the forces shown above. If the forces are balanced, the aircraft cruises at constant velocity. If the forces are unbalanced, the aircraft accelerates in the direction of the largest force.

Note that the job of the engine is just to overcome the drag of the airplane, not to lift the airplane. An airliner weighing 1 million pounds has four engines that produce a total of 200,000 pounds of thrust. The wings are doing the lifting, not the engines. In fact, there are some aircraft, called gliders, that have no engines at all, but fly just fine. Some external source of power has to be applied to initiate the motion necessary for the wings to produce lift. But during flight, the weight is opposed by both lift and drag. Paper airplanes are the most obvious example, but there are many kinds of gliders. Some gliders are piloted and are towed aloft by a powered aircraft, then cut free to glide for long distances before landing. During re-entry and landing, the space shuttle is a glider; the rocket engines are used only to loft the shuttle into space.

Quiz

- 1 Which paragraph in the section "Thrust" BEST reflects the central idea that it is the combination of all four forces that allows planes to fly effectively?

- 2 Which of the following selections from the article BEST develops a central idea?
 - (A) A force may be thought of as a push or pull in a specific direction. A force is a vector quantity, so a force has both a magnitude and a direction.
 - (B) The weight is distributed throughout the airplane. But we can often think of it as collected and acting through a single point called the center of gravity.
 - (C) Flying encompasses two major problems: overcoming the weight of an object by some opposing force, and controlling the object in flight.
 - (D) The center of pressure is defined just like the center of gravity, but using the pressure distribution around the body instead of the weight distribution.

- 3 Read the following sentence from the section "Weight."

Flying encompasses two major problems: overcoming the weight of an object by some opposing force, and controlling the object in flight.

Which of the following is the BEST substitute for the word "opposing" above?

- (A) different
- (B) competing
- (C) divergent
- (D) hostile

- 4 Read the selection from the section "Lift."

Airplanes generate an opposing force called lift to overcome the weight force. Lift is generated by the motion of the airplane through the air and is an aerodynamic force. "Aero" stands for the air, and "dynamic" denotes motion. Lift is directed perpendicular to the flight direction. The magnitude of the lift depends on several factors including the shape, size and velocity of the aircraft.

Adding which of these sentences to the end of this selection would help explain the meaning of the word "velocity" in the context of the article?

- (A) The speed and direction of the wind also affects the lift.
- (B) As the speed of the plane increases, lift also increases.
- (C) Velocity is the most important of these factors in determining lift.
- (D) The size and shape of the wings may play a significant role in determining velocity.