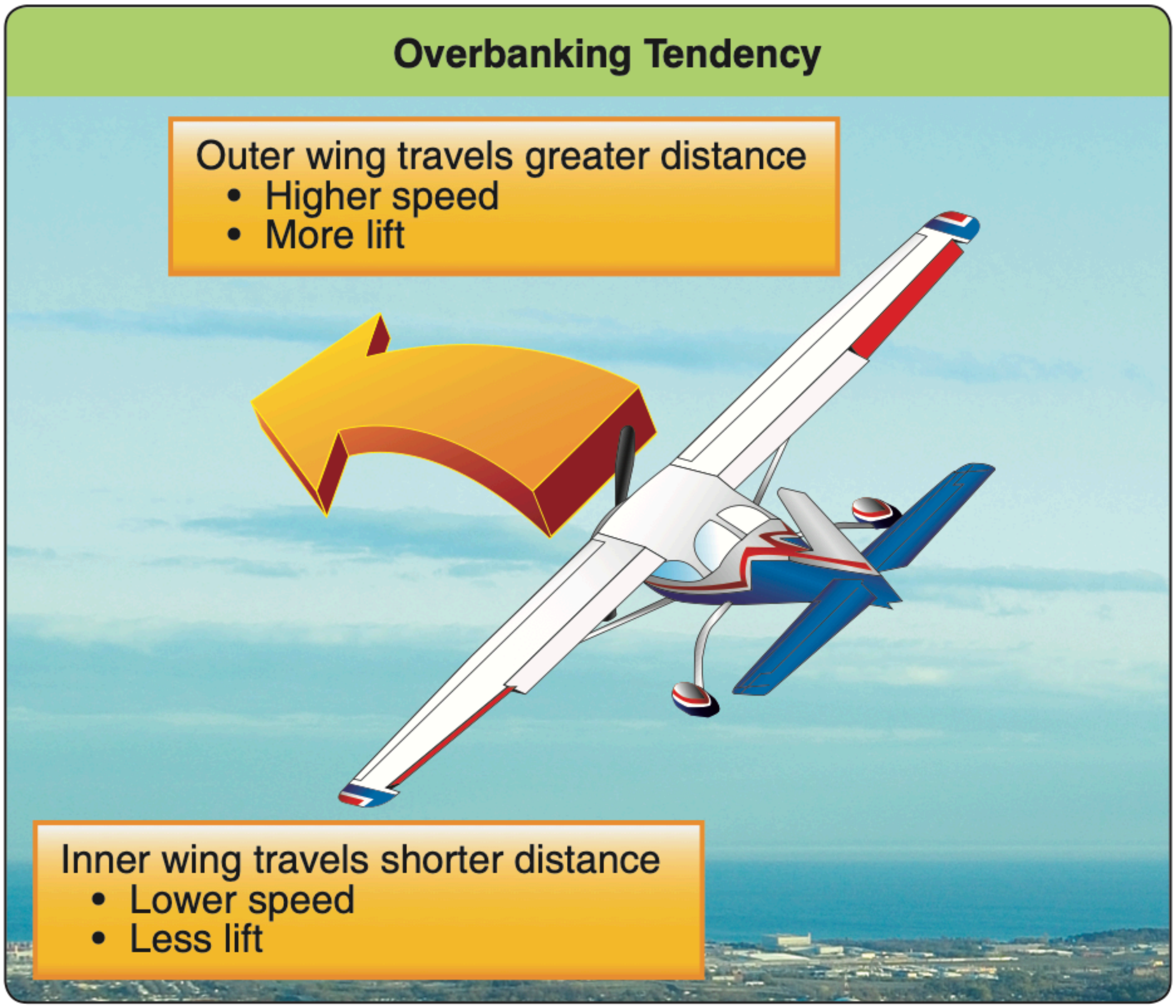


Figure 3-15. *Overbanking tendency.*

Why does a plane fly?

1. When going fast (cruise), mostly due to Mr Bernouli
2. When going slow (slow flight), Mostly due to Mr Newton (Third Law)

Bernoulli's Principle of Differential Pressure

A half-century after Newton formulated his laws, Daniel Bernoulli, a Swiss mathematician, explained how the pressure of a moving fluid (liquid or gas) varies with its speed of motion. Bernoulli's Principle states that as the velocity of a moving fluid (liquid or gas) increases, the pressure within the fluid decreases. This principle explains what happens to air passing over the curved top of the airplane wing.

A practical application of Bernoulli's Principle is the venturi tube. The venturi tube has an air inlet that narrows to a throat (constricted point) and an outlet section that increases in diameter toward the rear. The diameter of the outlet is the same as that of the inlet. The mass of air entering the tube must exactly equal the mass exiting the tube. At the constriction, the speed must increase to allow the same amount of air to pass in the same amount of time as in all other parts of the tube. When the air speeds up, the pressure also decreases. Past the constriction, the airflow slows and the pressure increases. *[Figure 4-4]*

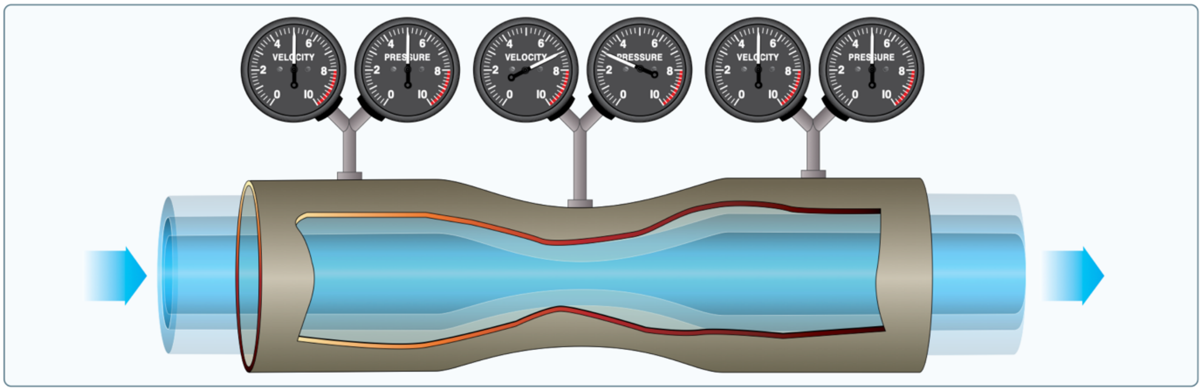


Figure 4-4. *Air pressure decreases in a venturi tube.*

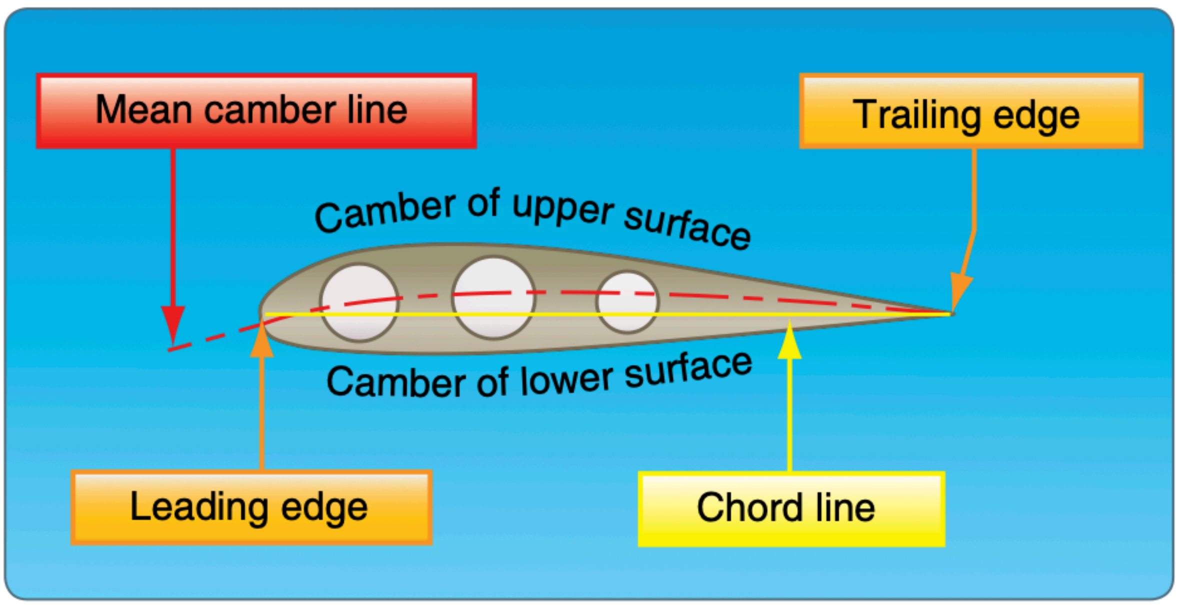


Figure 4-5. *Typical airfoil section.*

Since air is recognized as a body, and it is understood that air will follow the above laws, one can begin to see how and why an airplane wing develops lift. As the wing moves through the air, the flow of air across the curved top surface increases in velocity creating a low-pressure area.

Although Newton, Bernoulli, and hundreds of other early scientists who studied the physical laws of the universe did not have the sophisticated laboratories available today, they provided great insight to the contemporary viewpoint of how lift is created.

An airfoil is constructed in such a way that its shape takes advantage of the air's response to certain physical laws. This develops two actions from the air mass: a positive pressure lifting action from the air mass below the wing, and a negative pressure lifting action from lowered pressure above the wing.

As the air stream strikes the relatively flat lower surface of a wing or rotor blade when inclined at a small angle to its direction of motion, the air is forced to rebound downward, causing an upward reaction in positive lift. At the same time, the air stream striking the upper curved section of the leading edge is deflected upward. An airfoil is shaped to cause an action on the air, and forces air downward, which provides an equal reaction from the air, forcing the airfoil upward. If a wing is constructed in such form that it causes a lift force greater than the weight of the aircraft, the aircraft will fly.

If all the lift required were obtained merely from the deflection of air by the lower surface of the wing, an aircraft would only need a flat wing like a kite. However, the balance of the lift needed to support the aircraft comes from the flow of air above the wing. Herein lies the key to flight.

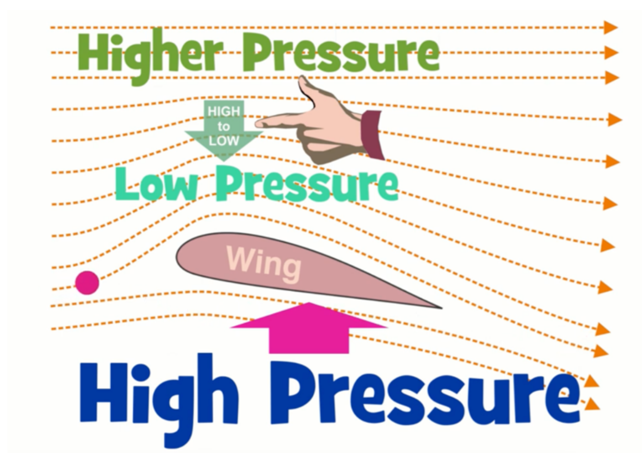
It is neither accurate nor useful to assign specific values to the percentage of lift generated by the upper surface of an airfoil versus that generated by the lower surface. These are not constant values. They vary, not only with flight conditions, but also with different wing designs.

Different airfoils have different flight characteristics. Many thousands of airfoils have been tested in wind tunnels and in actual flight, but no one airfoil has been found that satisfies every flight requirement. The weight, speed, and purpose of each aircraft dictate the shape of its airfoil. The most efficient airfoil for producing the greatest lift is one that has a concave or "scooped out" lower surface. As a fixed design, this type of airfoil sacrifices too much speed while producing

Low Pressure Above

In a wind tunnel or in flight, an airfoil is simply a streamlined object inserted into a moving stream of air. If the airfoil profile were in the shape of a teardrop, the speed and the pressure changes of the air passing over the top and bottom would be the same on both sides. But if the teardrop shaped airfoil were cut in half lengthwise, a form resembling the basic airfoil (wing) section would result. If the airfoil were then inclined so the airflow strikes it at an angle, the air moving over the upper surface would be forced to move faster than the air moving along the bottom of the airfoil. This increased velocity reduces the pressure above the airfoil.

Applying Bernoulli's Principle of Pressure, the increase in the speed of the air across the top of an airfoil produces a



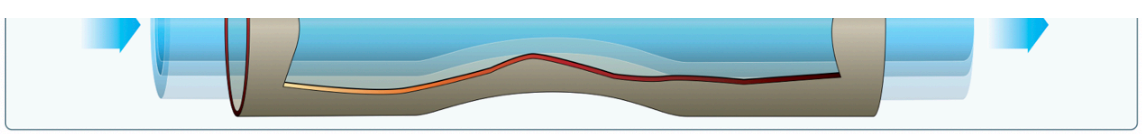


Figure 4-4. *Air pressure decreases in a venturi tube.*

The wing pushes the air up, just like in the bottom half of the venturi tube.

drop in pressure. This lowered pressure is a component of total lift. The pressure difference between the upper and lower surface of a wing alone does not account for the total lift force produced.

The downward backward flow from the top surface of an airfoil creates a downwash. This downwash meets the flow from the bottom of the airfoil at the trailing edge. Applying Newton's third law, the reaction of this downward backward flow results in an upward forward force on the airfoil.

High Pressure Below

A certain amount of lift is generated by pressure conditions underneath the airfoil. Because of the manner in which air flows underneath the airfoil, a positive pressure results, particularly at higher angles of attack. However, there is another aspect to this airflow that must be considered. At a point close to the leading edge, the airflow is virtually stopped (stagnation point) and then gradually increases speed. At some point near the trailing edge, it again reaches a velocity equal to that on the upper surface. In conformance with Bernoulli's principle, where the airflow was slowed beneath the airfoil, a positive upward pressure was created (i.e., as the fluid speed decreases, the pressure must increase). Since the pressure differential between the upper and lower surface of the airfoil increases, total lift increases. Both Bernoulli's Principle and Newton's Laws are in operation whenever lift is being generated by an airfoil.

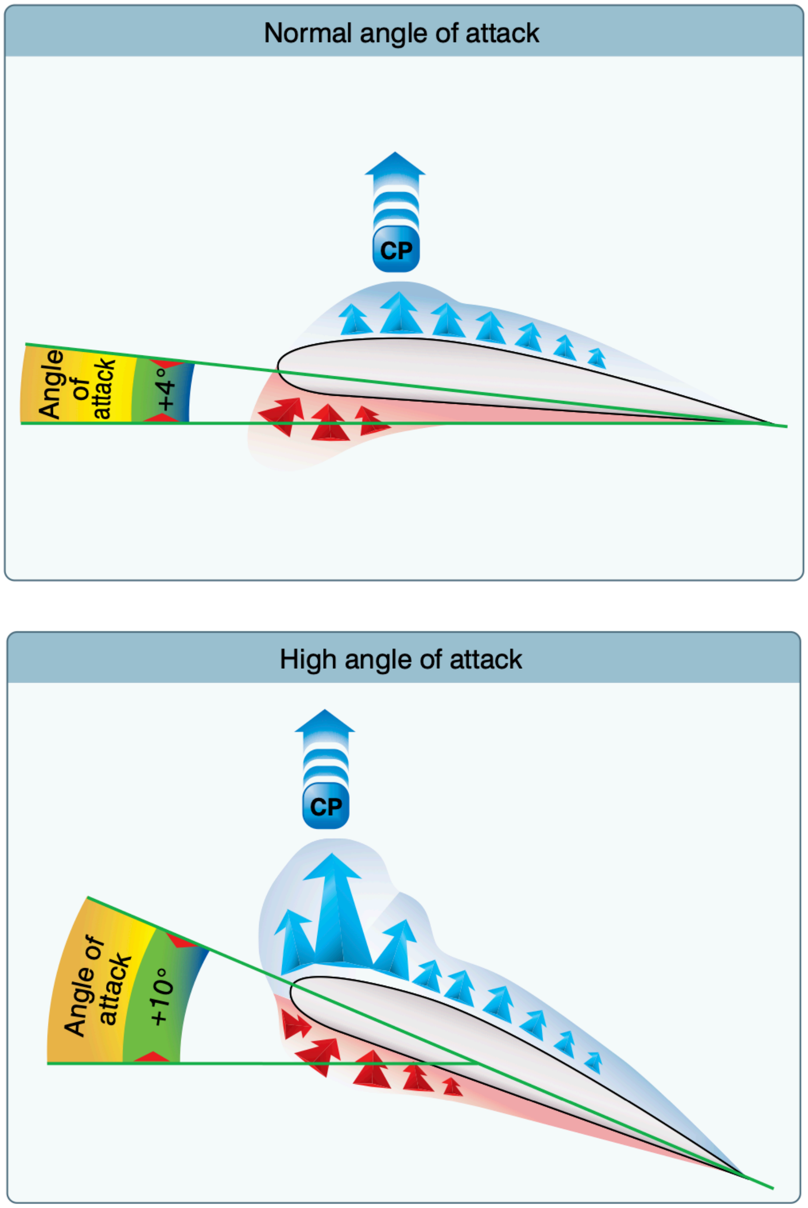
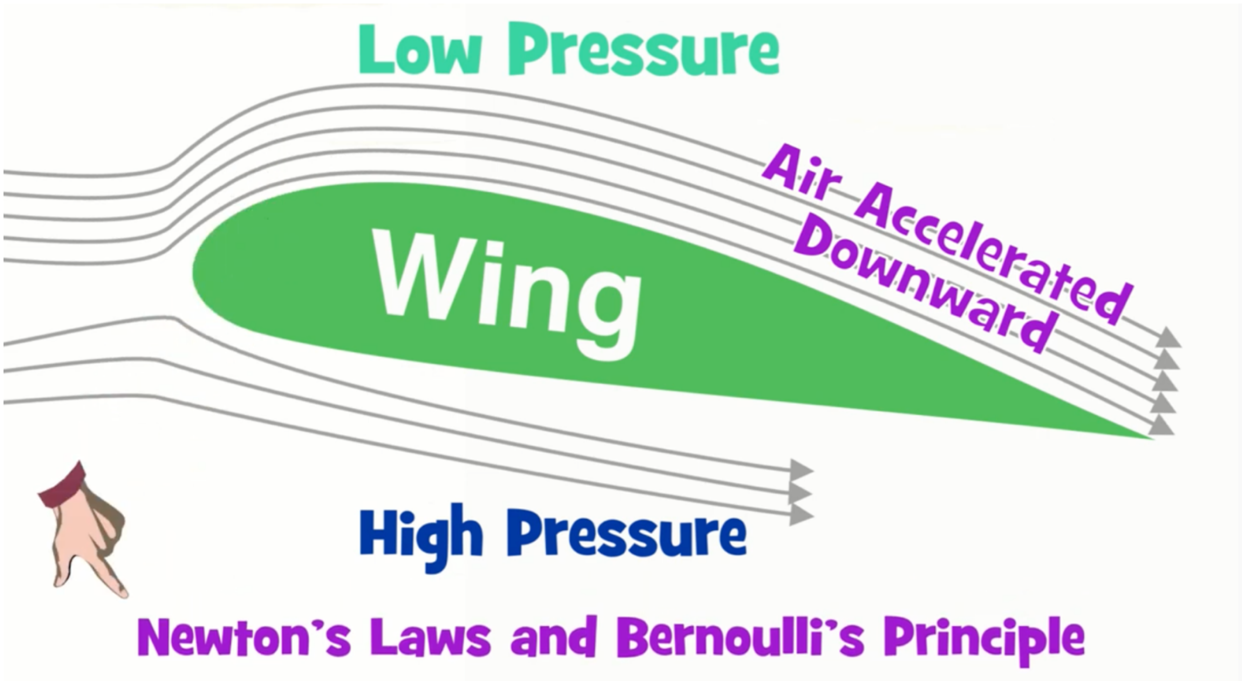


Figure 4-7. *Pressure distribution on an airfoil and CP changes with AOA.*

Bernoulli’s lift is shown in Blue.
Newton’s lift is shown in Red.

As the angle of attack increases, Newton becomes a greater part of the lift generated.


Low Pressure
Air Accelerated
Downward
Wing
High Pressure
Newton's Laws and Bernoulli's Principle

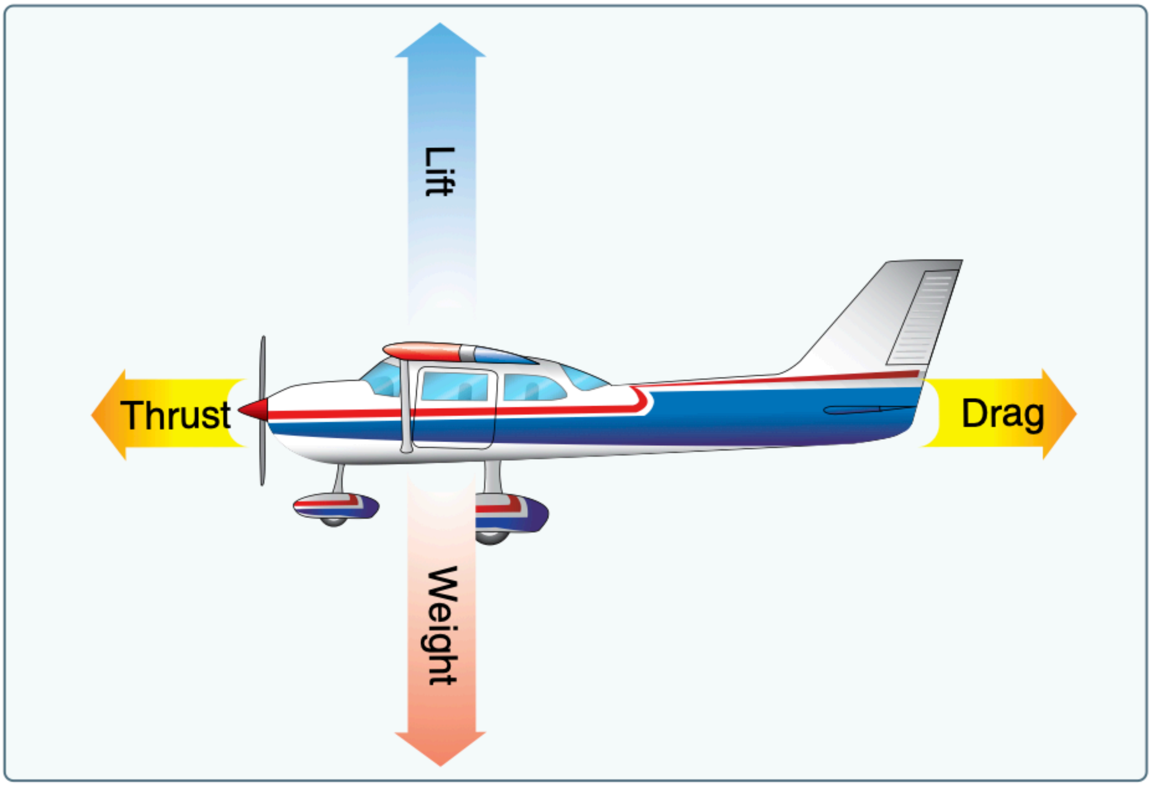


Figure 5-1. *Relationship of forces acting on an aircraft.*

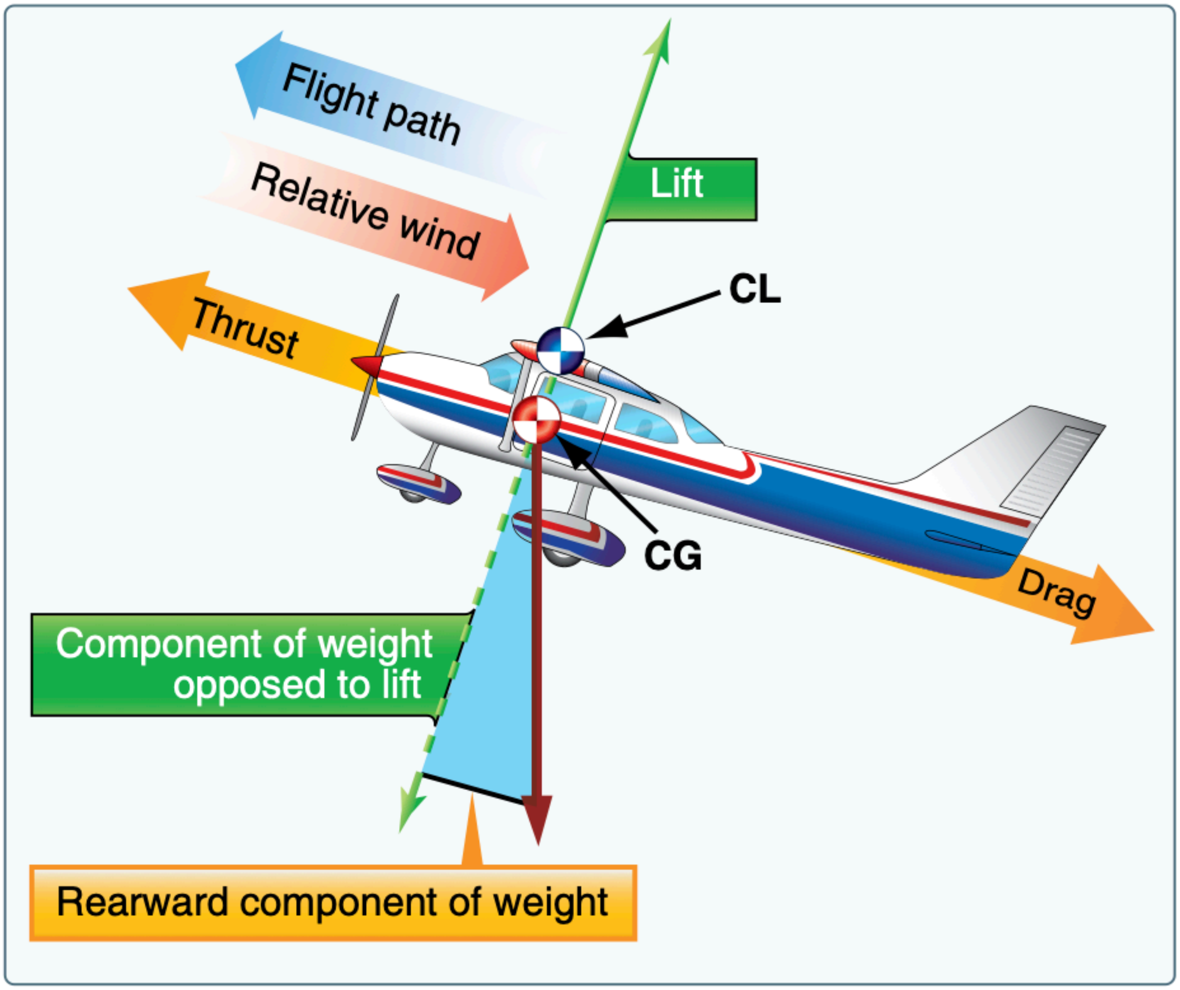


Figure 5-2. *Force vectors during a stabilized climb.*

Be able to draw from memory the forces in a stabilized climb.

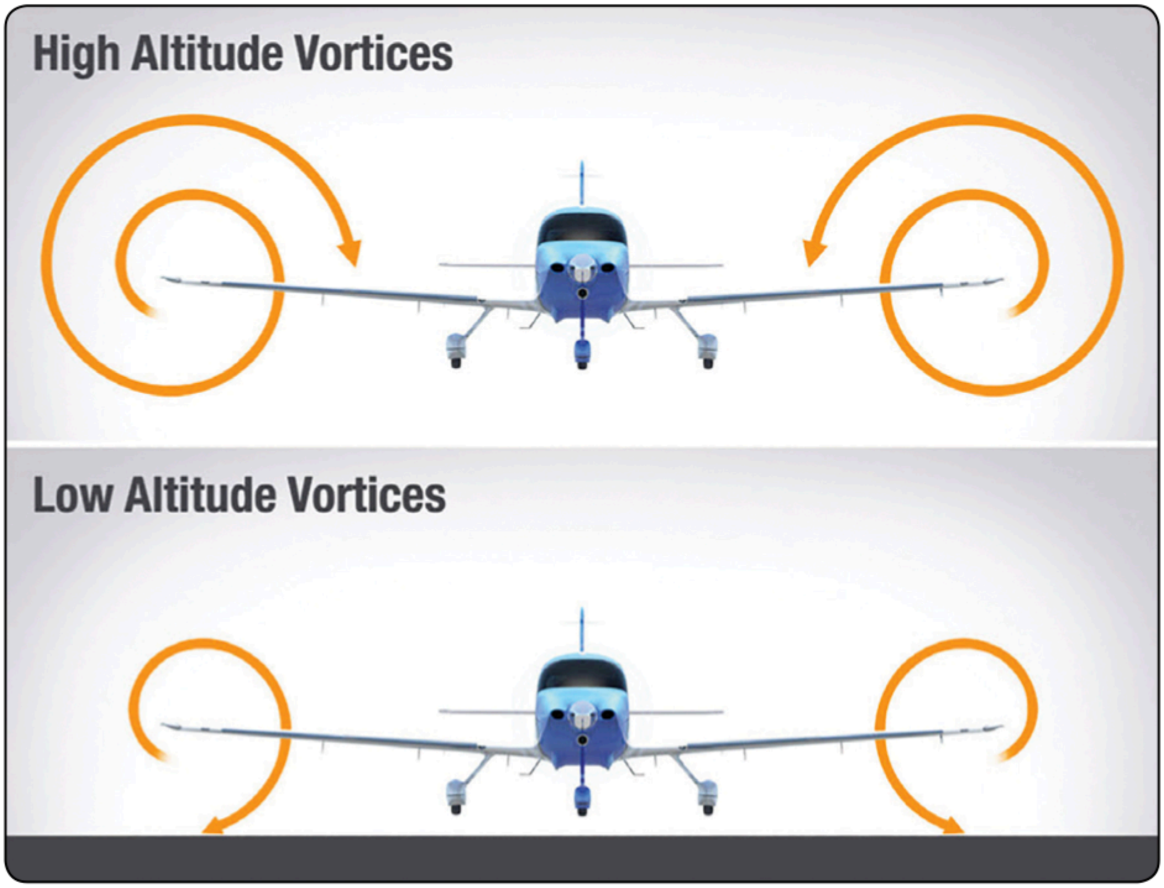


Figure 5-10. *The difference in wingtip vortex size at altitude versus near the ground.*

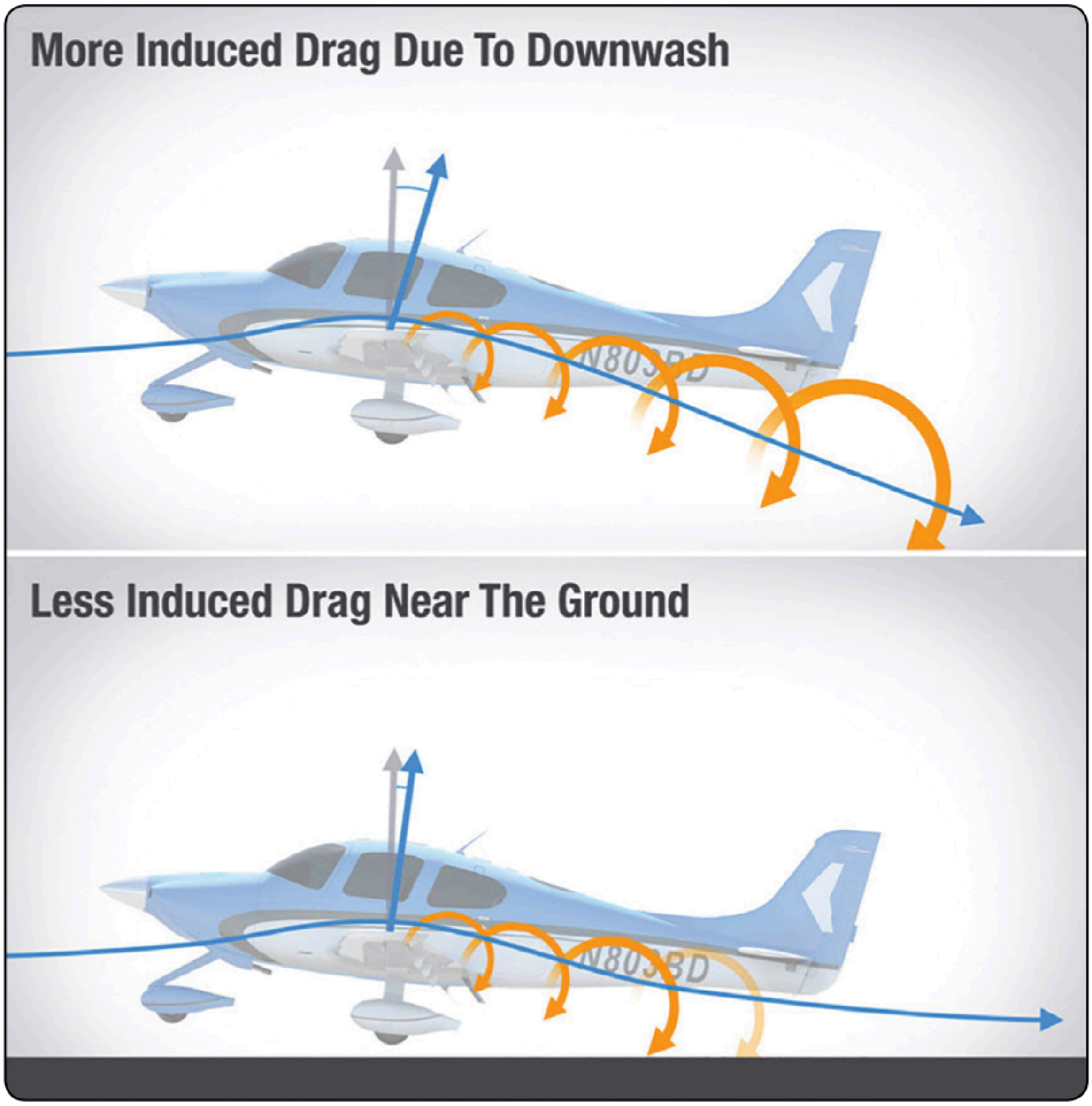


Figure 5-11. *The difference in downwash at altitude versus near the ground.*

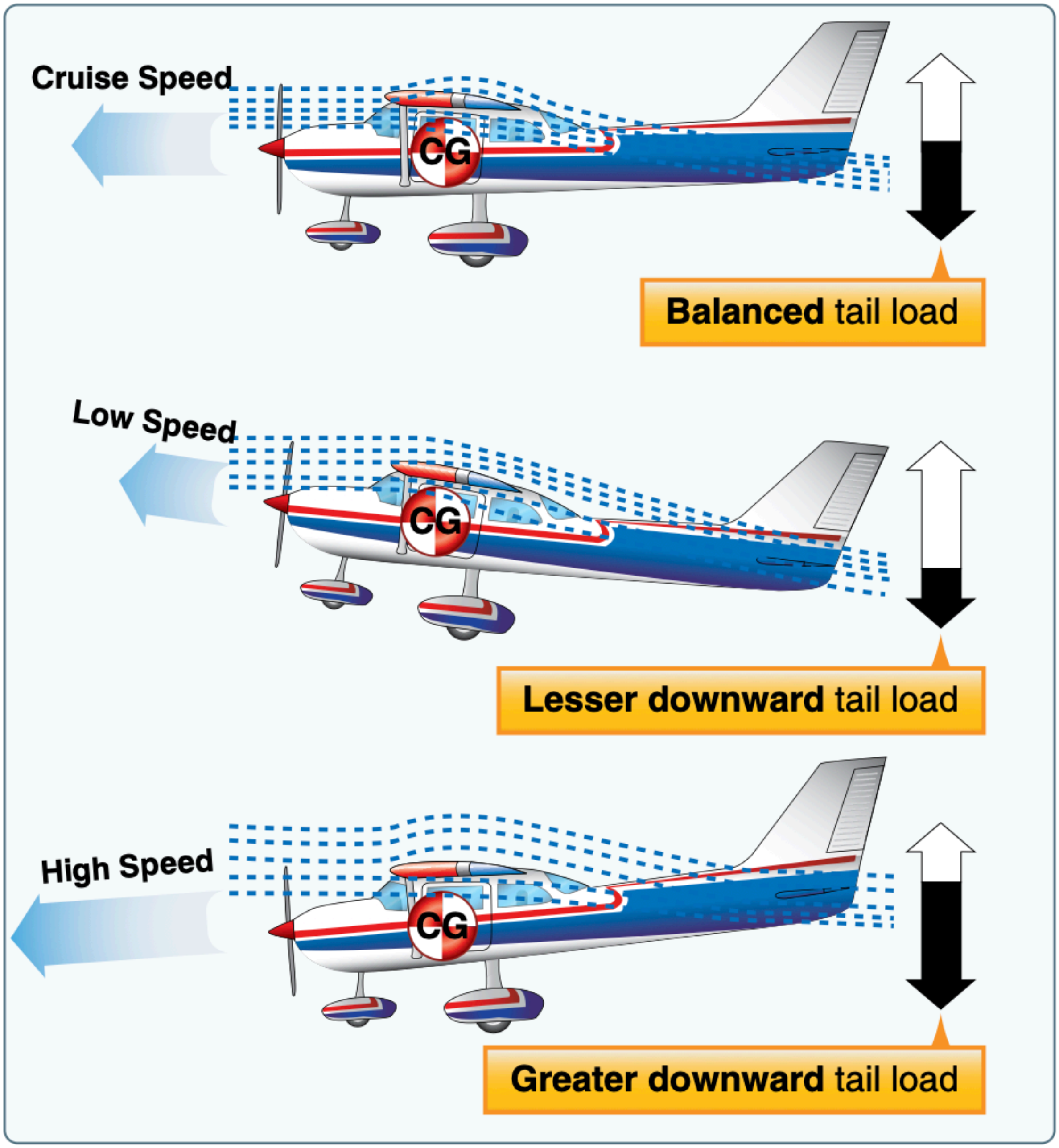


Figure 5-24. *Effect of speed on downwash.*

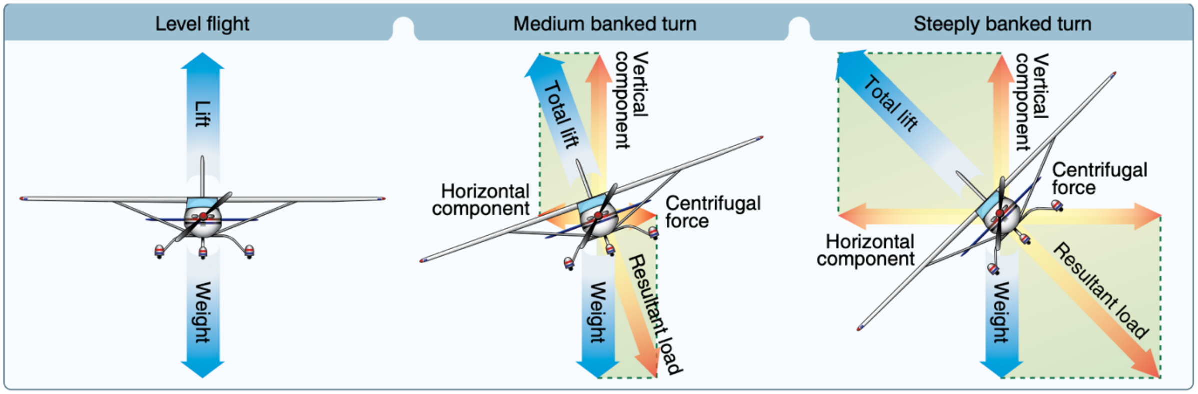


Figure 5-34. *Forces during normal, coordinated turn at constant altitude.*

Be able to draw from memory the forces in a turn.

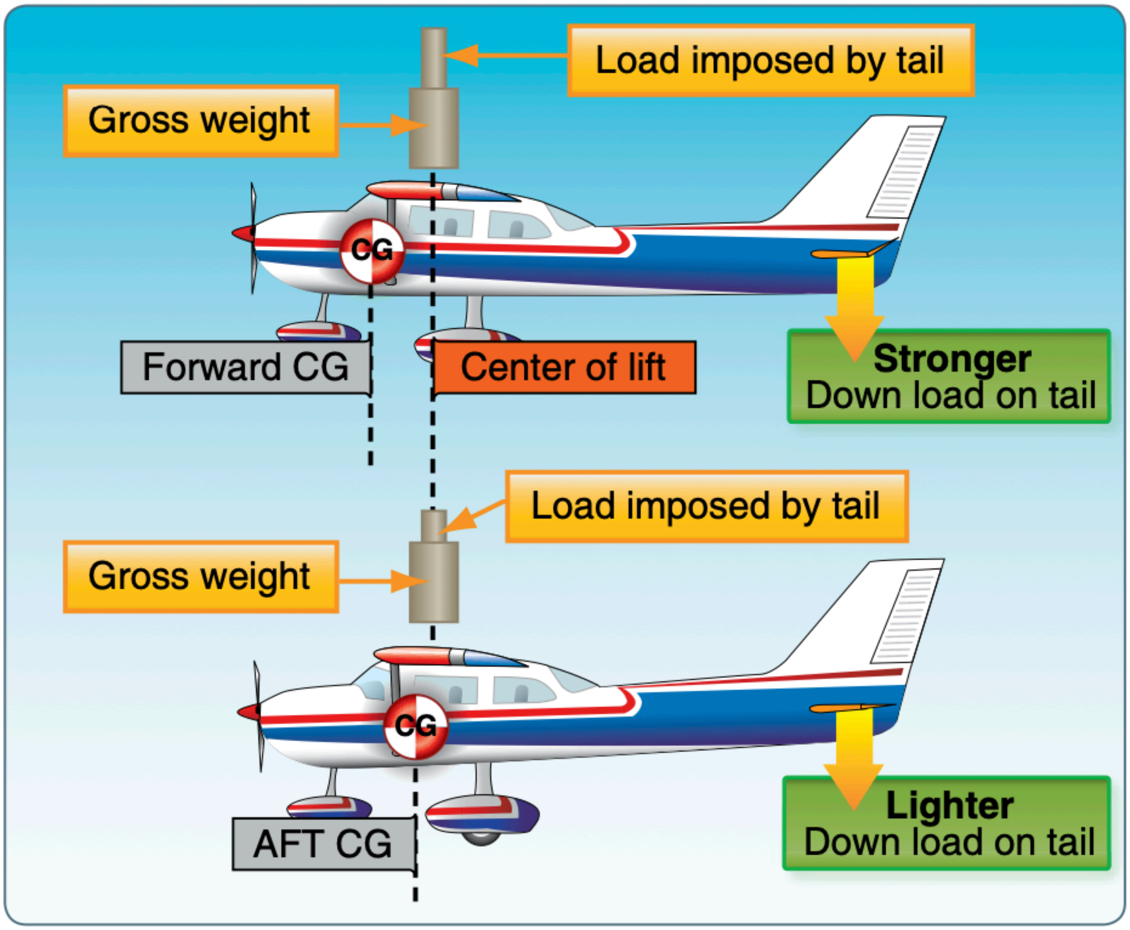


Figure 5-63. *Effect of load distribution on balance.*

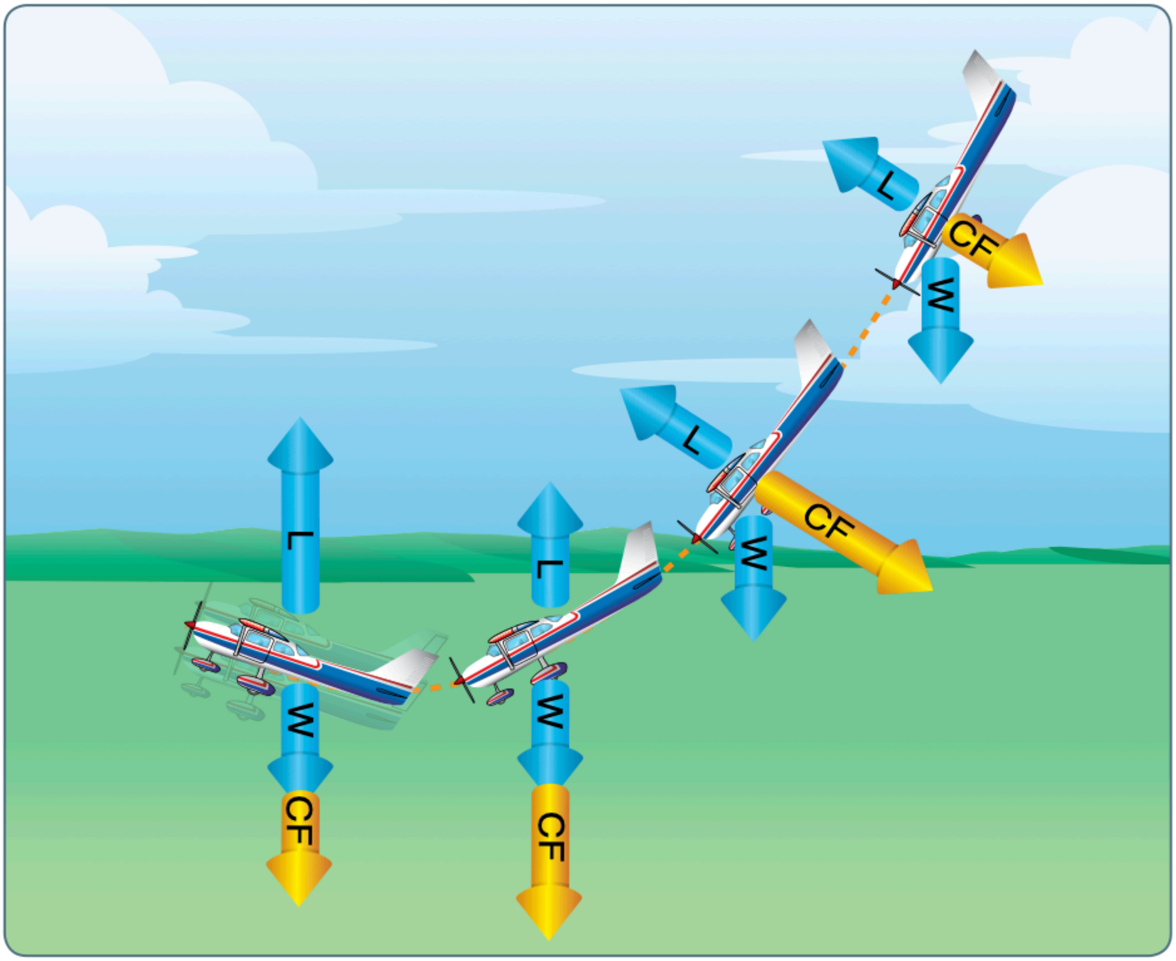


Figure 5-38. *Forces exerted when pulling out of a dive.*

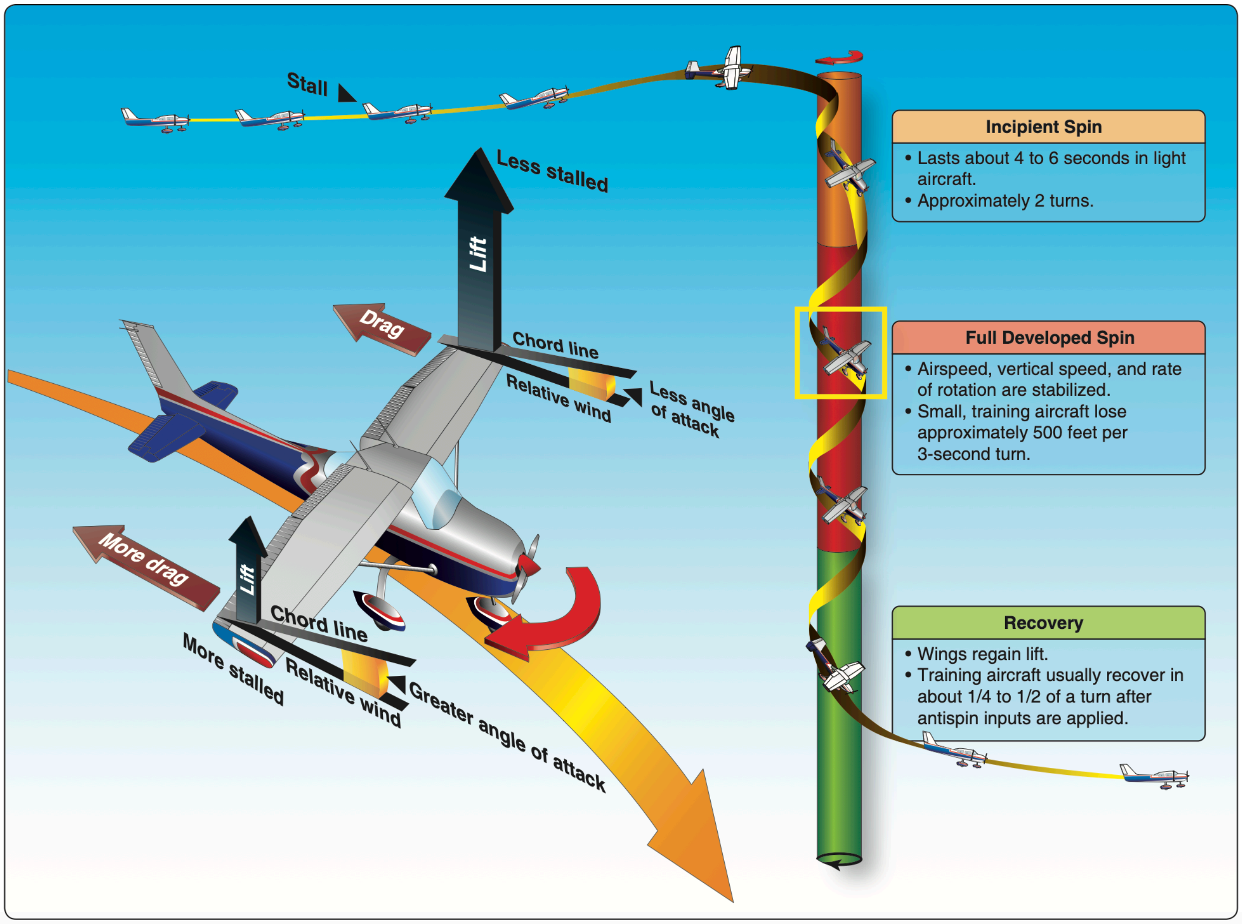


Figure 4-12. *Spin entry and recovery.*

Be able to draw from memory the forces on a plane in a spin.