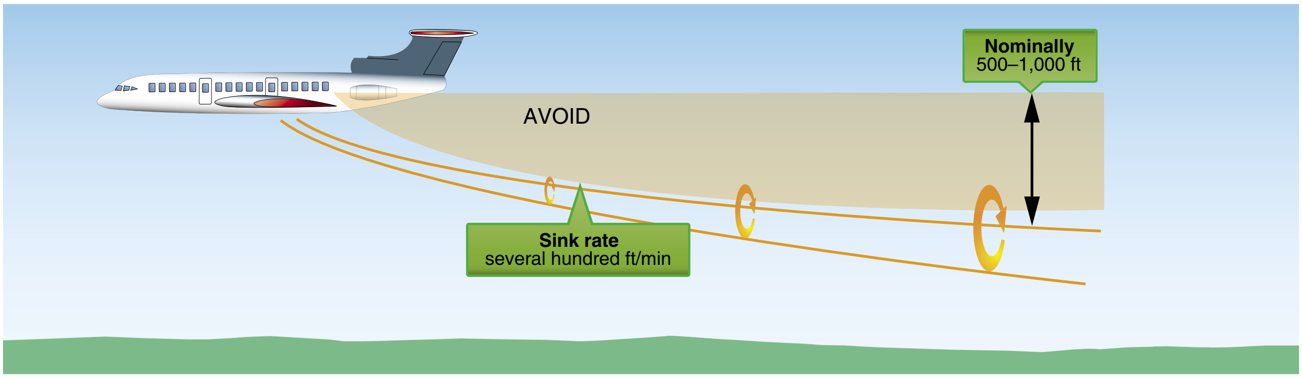

Figure 4-11. *Avoid following another aircraft at an altitude within 1,000 feet.*

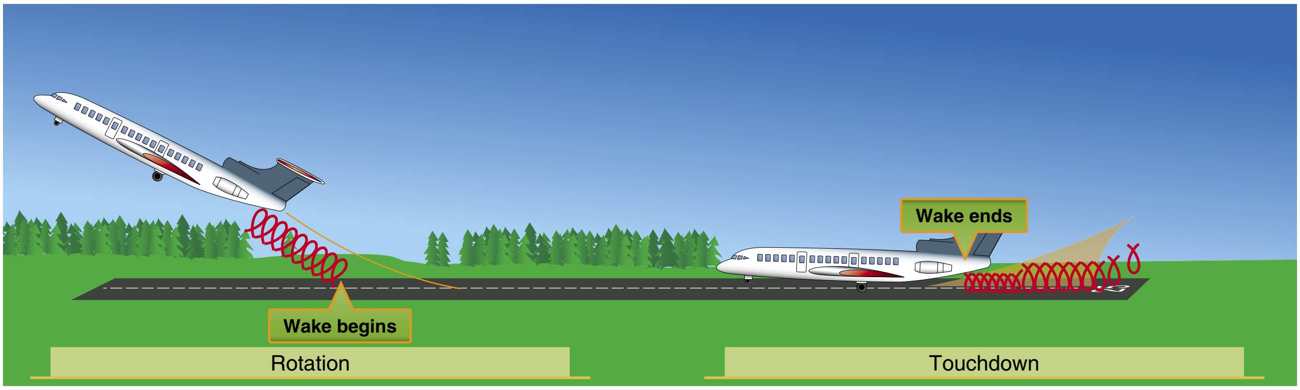

Figure 4-12. *Avoid turbulence from another aircraft.*

Wind is an important factor in avoiding wake turbulence because wingtip vortices drift with the wind at the speed of the wind. For example, a wind speed of 10 knots causes the vortices to drift at about 1,000 feet in a minute in the wind direction. When following another aircraft, a pilot should consider wind speed and direction when selecting an intended takeoff or landing point. If a pilot is unsure of the other aircraft's takeoff or landing point, approximately 3 minutes provides a margin of safety that allows wake turbulence dissipation. For more information on wake turbulence, see Advisory Circular 90-23.

Ground Effect

It is possible to fly an aircraft just clear of the ground (or water) at a slightly slower airspeed than that required to sustain level flight at higher altitudes. This is the result of a phenomenon better known of than understood even by some experienced pilots.

When an aircraft in flight comes within several feet of the surface, ground or water, a change occurs in the three-dimensional flow pattern around the aircraft because the vertical component of the airflow around the wing is restricted by the surface. This alters the wing's upwash, downwash, and wingtip vortices. *[Figure 4-13]* Ground effect, then, is due to the interference of the ground (or water) surface with the airflow patterns about the aircraft in flight.

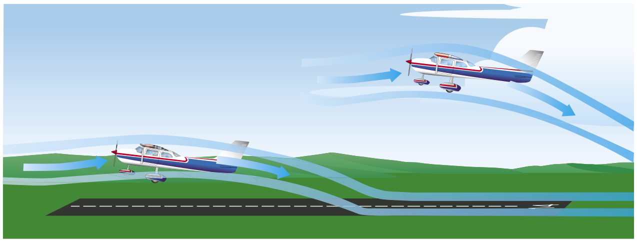

Figure 4-13. *Ground effect changes airflow.*

While the aerodynamic characteristics of the tail surfaces and the fuselage are altered by ground effect, the principal effects due to proximity of the ground are the changes in the aerodynamic characteristics of the wing. As the wing encounters ground effect and is maintained at a constant lift coefficient, there is consequent reduction in the upwash, downwash, and wingtip vortices.

Induced drag is a result of the airfoil's work of sustaining the aircraft, and a wing or rotor lifts the aircraft simply by accelerating a mass of air downward. It is true that reduced pressure on top of an airfoil is essential to lift, but that is only one of the things contributing to the overall effect of pushing an air mass downward. The more downwash there is, the harder the wing pushes the mass of air down. At high angles of attack, the amount of induced drag is high; since this corresponds to lower airspeeds in actual flight, it can be said that induced drag predominates at low speed.

However, the reduction of the wingtip vortices due to ground effect alters the spanwise lift distribution and reduces the induced AOA and induced drag. Therefore, the wing will require a lower AOA in ground effect to produce the same C_L. If a constant AOA is maintained, an increase in C_L results. *[Figure 4-14]*

Ground effect also alters the thrust required versus velocity. Since induced drag predominates at low speeds, the reduction of induced drag due to ground effect will cause the most significant reduction of thrust required (parasite plus induced drag) at low speeds.

The reduction in induced flow due to ground effect causes a significant reduction in induced drag but causes no direct effect on parasite drag. As a result of the reduction in induced drag, the thrust required at low speeds will be reduced. Due to the change in upwash, downwash, and wingtip vortices, there may be a change in position (installation) error of the airspeed system, associated with ground effect. In the majority of cases, ground effect will cause an increase in the local pressure at the static source and produce a lower indication of airspeed and altitude. Thus, an aircraft may be airborne at an indicated airspeed less than that normally required.

In order for ground effect to be of significant magnitude, the wing must be quite close to the ground. One of the direct results of ground effect is the variation of induced drag with wing height above the ground at a constant C_L. When the wing is at a height equal to its span, the reduction in induced drag is only 1.4 percent. However, when the wing is at a height equal to one-fourth its span, the reduction in induced drag is 23.5 percent and, when the wing is at a height equal to one-tenth its span, the reduction in induced drag is 47.6 percent. Thus, a large reduction in induced drag will take place only when the wing is very close to the ground. Because of this variation, ground effect is most usually recognized during the liftoff for takeoff or just prior to touchdown when landing.

During the takeoff phase of flight, ground effect produces some important relationships. An aircraft leaving ground effect after takeoff encounters just the reverse of an aircraft entering ground effect during landing; i.e., the aircraft leaving ground effect will:

- Require an increase in AOA to maintain the same C_L.
- Experience an increase in induced drag and thrust required.
- Experience a decrease in stability and a nose-up change in moment.
- Experience a reduction in static source pressure and increase in indicated airspeed.

Ground effect must be considered during takeoffs and landings. For example, if a pilot fails to understand the relationship between the aircraft and ground effect during takeoff, a hazardous situation is possible because the recommended takeoff speed may not be achieved. Due to the reduced drag in ground effect, the aircraft may seem capable of takeoff well below the recommended speed. As the aircraft rises out of ground effect with a deficiency of speed, the greater induced drag may result in marginal initial climb performance. In extreme conditions, such as high gross weight, high density altitude, and high temperature, a deficiency of airspeed during takeoff may permit the aircraft to become airborne but be incapable of sustaining flight out of ground effect. In this case, the aircraft may become airborne initially with a deficiency of speed, and then settle back to the runway.

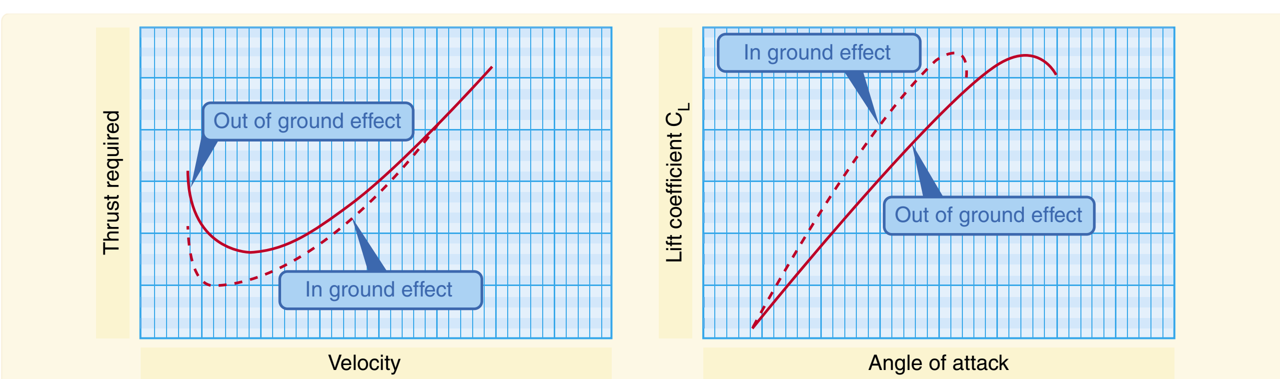

Figure 4-14. *Ground effect changes drag and lift.*

A pilot should not attempt to force an aircraft to become airborne with a deficiency of speed. The manufacturer's recommended takeoff speed is necessary to provide adequate initial climb performance. It is also important that a definite climb be established before a pilot retracts the landing gear or flaps. Never retract the landing gear or flaps prior to establishing a positive rate of climb, and only after achieving a safe altitude.

If, during the landing phase of flight, the aircraft is brought into ground effect with a constant AOA, the aircraft experiences an increase in C_L and a reduction in the thrust required, and a "floating" effect may occur. Because of the reduced drag and power-off deceleration in ground effect, any excess speed at the point of flare may incur a considerable "float" distance. As the aircraft nears the point of touchdown, ground effect is most realized at altitudes less than the wingspan. During the final phases of the approach as the aircraft nears the ground, a reduced power setting is necessary or the reduced thrust required would allow the aircraft to climb above the desired glidepath (GP).

Axes of an Aircraft

The axes of an aircraft are three imaginary lines that pass through an aircraft's CG. The axes can be considered as imaginary axles around which the aircraft turns. The three axes pass through the CG at 90° angles to each other. The axis from nose to tail is the longitudinal axis, the axis that passes from wingtip to wingtip is the lateral axis, and the axis that passes vertically through the CG is the vertical axis. Whenever an aircraft changes its flight attitude or position in flight, it rotates about one or more of the three axes. *[Figure 4-15]*

The aircraft's motion about its longitudinal axis resembles the roll of a ship from side to side. In fact, the names used to describe the motion about an aircraft's three axes were originally nautical terms. They have been adapted to aeronautical terminology due to the similarity of motion of aircraft and seagoing ships. The motion about the aircraft's longitudinal axis is "roll," the motion about its lateral axis is "pitch," and the motion about its vertical axis is "yaw." Yaw is the horizontal (left and right) movement of the aircraft's nose.

The three motions of the conventional airplane (roll, pitch, and yaw) are controlled by three control surfaces. Roll is controlled by the ailerons; pitch is controlled by the elevators; yaw is controlled by the rudder. The use of these controls is explained in Chapter 5, Flight Controls. Other types of aircraft may utilize different methods of controlling the movements about the various axes.

For example, weight-shift control aircraft control two axes, roll and pitch, using an "A" frame suspended from the flexible wing attached to a three-wheeled carriage. These aircraft are controlled by moving a horizontal bar (called a control bar) in roughly the same way hang glider pilots fly. *[Figure 4-16]* They are termed weight-shift control aircraft

Figure 4-16. *A weight-shift control aircraft.*

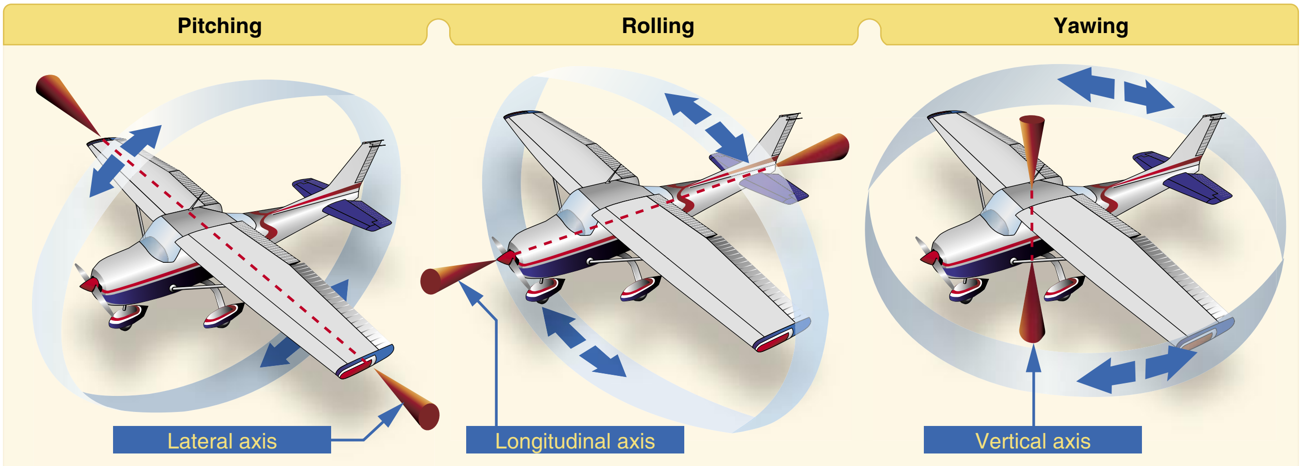

Figure 4-15. *Axes of an airplane.*