Ground Effect

How it can work for — or against — you

by BARRY SCHIFF / AOPA 110803

■■ High above the Pacific, the Boeing 377 Stratocruiser droned along the great-circle route from Honolulu to San Francisco. Thus far, the flight had been routine. Not much to report other than a minor hydraulic leak.

The clouds below drifted by with metronomic regularity and Aircraft Commander Tyson was becoming weary. He glanced casually at the matrix of instruments before him, yawned compulsively, and took mental note of how difficult it was to stay awake. But Tyson didn't have time to consider how delicious such boredom can be.

Without warning, the four-bladed propeller separated from the number two, 27-cylinder engine and spun away toward infinity—but not before smashing into its companion engine on the same side. With "two churning and two burning," the heavily laden Stratocruiser began to descend. Tyson applied METO (maximum except takeoff) power to the two remaining engines on the right wing and eased back on the control yoke. But this wasn't sufficient to arrest the alarming sink rate. The calm waters of the Pacific were rising steadily.

Everyone aboard struggled into their Mae Wests and prepared nervously for the mid-Pacific ditching. But Tyson soon noticed a strange turn of events. When the crippled Boeing was within striking range of a healthy shark, the sink rate began to decrease. Seconds later, the aircraft began to hold its own and Tyson found that he was able to at least postpone what had appeared to be an inevitable swim.

Struggling against powerful, unbalancing forces, Tyson managed to avoid the continuously threatening stall. After hundreds of miles just mere feet above the water, sufficient fuel had been consumed to lighten the airplane and allow the flight to continue at not so precarious an altitude.

The dramatic discovery Tyson made about the performance characteristics of an aircraft at extremely low altitude was so profound that the phenomenon was named after him: T-effect. But now that the subject has been fully investigated and accurately explained, it is referred to as "ground effect."

The average pilot may not have or cherish the opportunity to experiment with ground effect during an oceanic crossing, but he does encounter it at least twice during every flight—when taking off and landing. The "ground cushion," as it is sometimes called, can be significantly influential during these operations.

Many pilots believe that ground effect is the result of air being compressed between the wing and the ground. Presumably, this increased air density creates a cushion beneath the wing and improves performance. This seems plausible, but is incorrect. Unfortunately, the FAA perpetuates this myth in its VFR Exam-O-Gram No. 47. So let's set the record straight. Air is not compressed between wing and ground.

Figure 1 shows the airflow about a wing. The streamlines separate at the leading edge and follow the upper and lower wing surfaces. This model is used almost universally to teach how a wing develops lift. But the diagram is too simplistic. It shows only an "airfoil section," a cross-sectional sliver of a wing. To appreciate the reality of

Figure 1

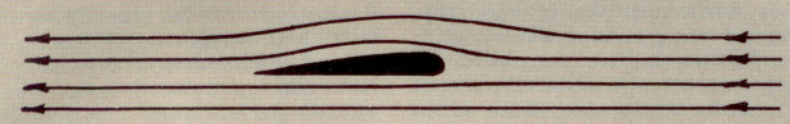


Figure 2

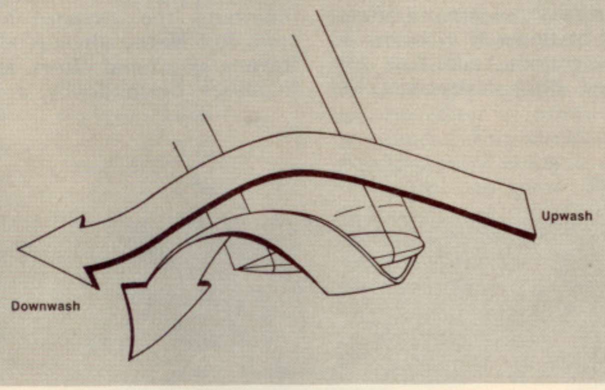
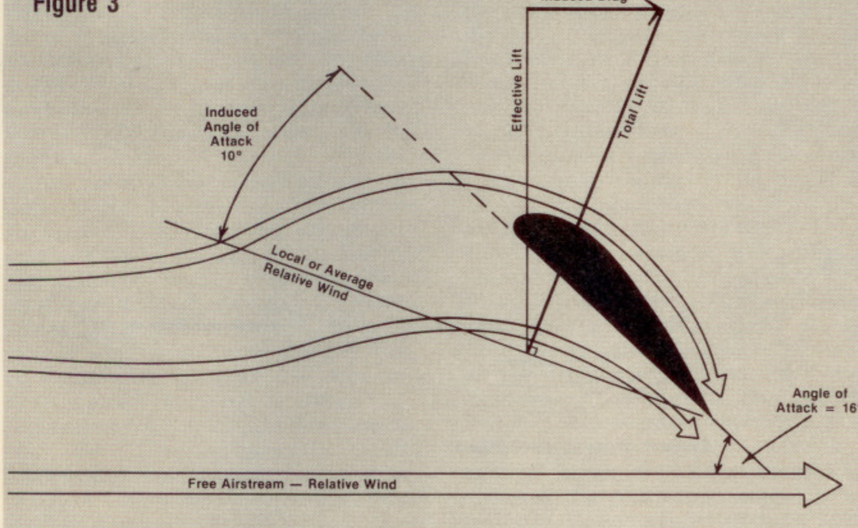


Figure 3



(angles exaggerated)

lift, the airflow about the entire wing must be investigated.

From the view shown in Figure 2, it can be seen that high-pressure air from beneath the wing attempts to curl over the tip toward the low-pressure region above the wing. This curling combines with the relative wind to produce a tornado of air—the wing-tip vortex (wake turbulence).

During slow flight when the angle of attack is larger, the difference in pressure beween the lower and upper wing surfaces is obviously greater and results in a stronger vortex. (This explains why wake turbulence is more intense behind a slow aircraft than a fast one.)

The effect of the vortices is to induce considerable "upwash" to air approaching the wing and "downwash" to the air flowing aft.

Figure 3 shows a wing in slow flight at a relatively large angle of attack while maintaining a constant altitude. The angle between the chord of the wing and the free airstream is 16 degrees. This is referred to as the wing's angle of attack. But because of the upwash coming from ahead of the wing, the *average* or *local* relative wind doesn't come from the same direction as the free airstream. The wing "feels" a relative wind induced by the immediately surrounding airflow which, at slow speeds, results in a smaller angle of attack than might be otherwise expected.

In this case, the "induced" angle of attack felt by the wing is only 10 degrees. Since lift acts perpendicular to the induced relative wind (not the free airstream), it can be seen that wing lift acts slightly rearward. The horizontal component of this rearward-acting lift is a retarding force called induced drag, an unavoidable byproduct of lift. Induced drag has the same detrimental effects as the more familiar parasite drag (skin friction, form drag, and interference drag). An increase in either induced or parasite drag requires additional power to maintain a constant airspeed. But while parasite drag increases with airspeed, induced drag lessens.

Conversely, induced drag increases rapidly as airspeed decreases. At just above stalling speed, for example, induced drag may account for more than 80% of the total drag acting upon an airplane. The remaining 20% (or less) is parasitic drag (air resistance).

Parasite drag can be reduced somewhat by cleaning the wings, substituting flush-mounted antennas for those that protrude, and making other minor aerodynamic improvements. With the exception of redesigning the aircraft, there's little else a pilot can do.

Absolutely nothing can be done about induced drag. It is the constant companion to lift (something most pilots are unwilling to sacrifice). But if induced drag *could* be reduced substantially, aircraft performance at large angles of attack would improve dramatically.

One way to reduce induced drag would be to decrease the amount of upwash ahead of the wing. And the only way to accomplish this would be to fly the wing very close to the ground. The degree of upwash would decrease because air preceding the wing wouldn't have enough room to develop any significant vertical motion. Also, the wing would produce less downwash. Air flowing from the trailing edge would be forced more parallel to the ground. Figure 4 shows the airflow about a wing being flown in and out of ground effect, the term used to describe the reduction of induced drag resulting from a wing being flown in close proximity to the ground.

Those are the basics. Ground effect is caused by a reduction of induced drag, not a compression of air beneath the wings.

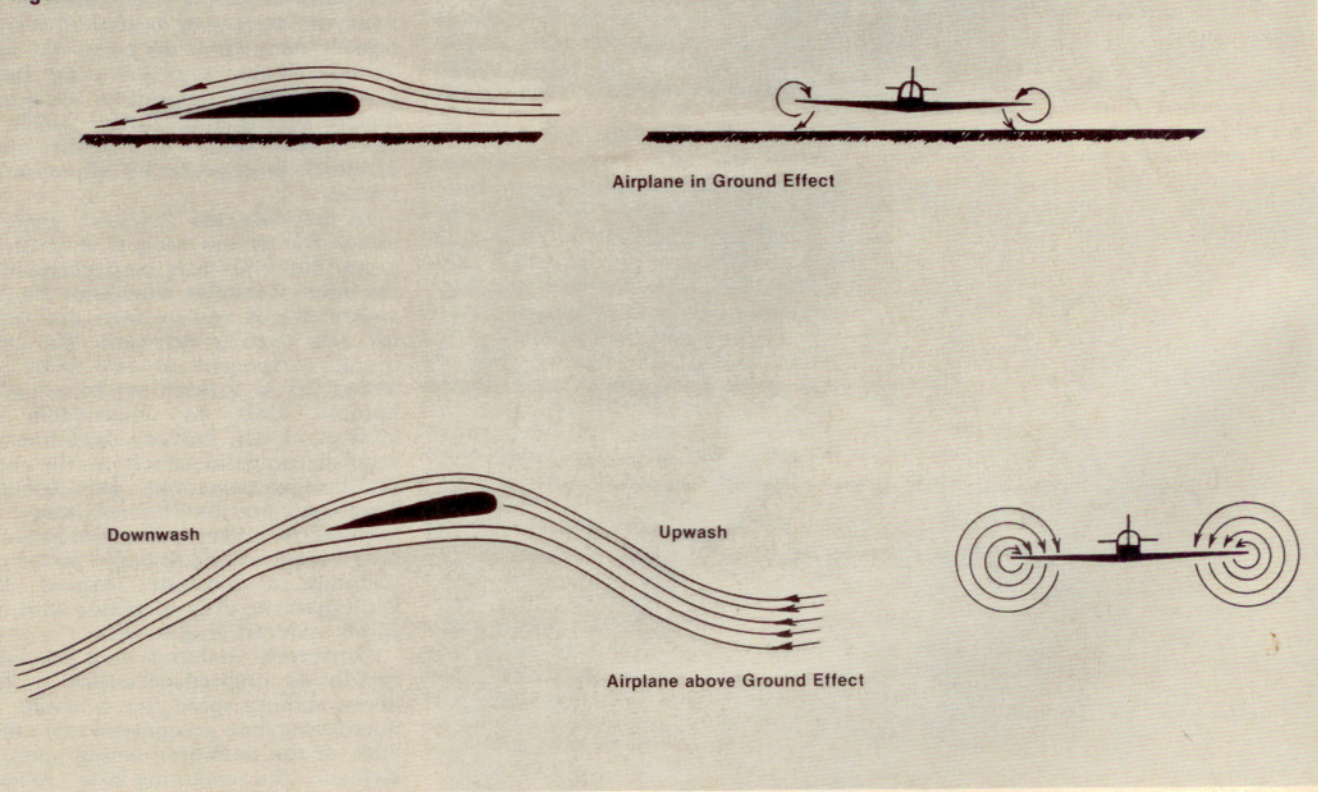
Notice from Figure 4 that wing-tip vortices also are reduced when the wing is flown near the ground. This is because the ground interferes with vortex formation. Reducing the diameter of a vortex also reduces induced drag, which creates the same effect as increasing the aspect ratio of the wing.

Ground effect doesn't have any measurable influence unless the wing is flown at an altitude no greater than its span—which is fairly close to the surface (see Table 1). A Cessna Cardinal, for example, has a wing span of 36 feet. To benefit from ground effect, the wing must be flown at or below 36 feet above the ground. At 36 feet, 2% of the induced drag disappears. At eighteen feet above the ground (half the wing span), 8% of the drag is eliminated. When flying at only nine feet (25% of the wing span), induced drag is reduced by 24%. If the wing could get to within three feet of the runway (which would require smashing the landing gear), more than half the induced drag would be eliminated.

It's evident, therefore, that low-wing aircraft usually are more influenced by ground effect than high-wing aircraft simply because a low wing can be flown closer to the ground. Nevertheless, high-wings are influenced by ground effect *almost* as noticeably. The reduction of induced drag enhances aircraft performance considerably. At times, embarrassingly so.

Consider the takeoff. As the hapless pilot urges his heavily laden aircraft along the runway, he notes the minimum "unstick" speed on the IAS gauge and abruptly rotates the nose skyward. Since he desires to impress his passengers with a maximum-angle climb, he maintains the airspeed barely above stall. But as the aircraft leaves the influence of ground effect, induced drag increases dramatically and the pilot

Figure 4



finds that his machine suddenly has a will of its own. It doesn't want to go anywhere.

The speed that enabled the airplane to climb at 4 feet isn't enough at 40. The pilot gets that uneasy feeling in the pit of his stomach as the ship begins to settle. But by now the runway has been left behind. Plane and pilot are about to land . . . in the sagebrush.

The pilot's mistake was simple. He tried to fly out of ground effect without sufficient airspeed and power to cope successfully with an inevitable 100% increase in induced drag.

Ratio of Wing Height (agl) to Wing Span	Percent Reduction of Induced Drag
.1	48%
.2	29%
.3	19%
.4	13%
.5	8%
.6	6%
.7	4%
.8	3%
.9	2½%
1.0	2%

Table 1

This type of accident occurs most frequently at high-density-altitude airports. Simply because an airplane has enough airspeed to get off the ground doesn't mean that it can climb above the influence of ground effect. A few feet of altitude can make the difference.

The point to remember is that additional power is required to compensate for increases in drag that occur as an airplane leaves ground effect. But during a takeoff climb, the engine is already developing maximum available power. If a pilot is climbing at the ragged edge without a cushion of airspeed, he may be unable to cope with a substantial increase in drag.

Those who fly retractable-gear aircraft should be particularly careful. Numerous accidents are caused annually by pilots who prematurely raise the landing gear. Settling back to the runway with the wheels in the wells is embarrassing, expensive, and dangerous. When takeoff and initial climb performance is marginal, delay raising the gear until safely above the influence of ground effect.

Although ground effect can lead the unsuspecting pilot astray, it also can be used to advantage. Since slow-speed performance is improved while in ground effect, why be in a hurry to leave it? The knowledgeable pilot will take off, lower the nose slightly, and maintain altitude just a few feet above the runway. This is because an airplane accelerates more rapidly in ground effect than above it.

A skillful pilot literally aims the aircraft at the obstacle over which he wishes to climb, seemingly in sheer defiance. Once a safe climb speed has been attained he raises the nose gingerly and soars over the trees with the maximum possible safety margin. This technique is considerably more efficient than *forcing* an aircraft into a premature climb.

After a heavily loaded takeoff from a critically short runway at high-density altitude, an airplane *may* climb satisfactorily to the upper limits of ground effect at minimum speed, but as induced drag steadily increases, the airplane may reach a point where it will climb no more. FAA files bulge with accident reports describing how pilots have mushed headlong into obstacles when acceleration in ground effect might have provided the performance necessary to climb safely.

Ground effect is noticeably influential also during landings. As an aircraft descends into ground effect at a constant attitude, induced drag decays rapidly and is made noticeable by a floating sensation. As a result, the aircraft often won't land until well beyond the original touchdown target. If the runway is too short, abort the landing and try again. More than one pilot has just sat there occupying space while waiting for the wheels to touch only to discover that the runway had receded behind him.

If a pilot is approaching the runway with excessive airspeed, he might consider reducing airspeed while *above* the influence of ground effect. This is where induced drag is most powerful and causes maximum deceleration. Or, if a pilot is caught short with his airspeed down, he might lower the nose and descend into ground effect where he can expect a drag reduction and a slightly prolonged glide. This is recommended only as an emergency measure and when the terrain preceding the runway is flat and unobstructed.

But if the touchdown target is halfway down a long runway, such as during a spot-landing contest where a premature landing doesn't smart so badly, then this playing with ground effect can impress the judges. Knowing precisely what ground effect can and cannot do for a particular aircraft, however, takes practice, lots of it.

After landing, some pilots prefer to keep the nose high and use aerodynamic braking to slow the aircraft. This is most effective when the wing is partially stalled. But because of the large reduction of induced drag caused by the wing being so close to the ground, aerodynamic braking is not as effective as using conventional brakes to decelerate (for most aircraft).

Another point to consider about ground effect is its influence on longitudinal or pitch stability. Remember the downwash of air that flows from the trailing edge of a wing? Normally, this descending air strikes the top of the horizontal stabilizer and helps to keep the tail down.

As an aircraft enters ground effect, downwash is reduced and the tail wants to rise. Unless the fuselage bends in the process, this causes the nose to drop slightly. This explains why an aircraft becomes slightly more nose-heavy immediately prior to touchdown. Experienced pilots expect this or simply react subconsciously; students learn the hard way and wonder why they tend to land nosewheel first. This is also why it is difficult to make a "hands-off" landing. As an airplane gets to within five or ten feet of the runway, it tends to pitch nose down.

Conversely, as a pilot climbs out of ground effect and downwash from the wing is restored, the tail becomes heavier and the nose wants to pitch up. This is of no help to a pilot climbing on the verge of a stall and emphasizes the foolishness of minimum-speed climbs.

This nose-up tendency is especially critical when flying an aircraft loaded at or beyond the rearward center-of-gravity limit. The aircraft might behave quite normally as the wheels leave the tarmac, but the pilot may be in for quite a surprise when the aircraft leaves the influence of ground effect and he has difficulty holding the nose down.

Ground effect also causes local increases in static pressure which cause the airspeed indicator and altimeter to indicate slightly less than they should. For the same reason, the rate-of-climb indicator usually indicates a descent during the takeoff roll.

Whether or not pilots are aware of it, ground effect plays a key role during every takeoff and landing. The knowledgeable pilot, however, is aware of how to use this phenomenon to his advantage. □