costly airplane landing facilities would constitute a deficit that could never be recouped. Second, a steady trend has been noted—and it has accelerated over the past decade—for the more progressive and promising business and industry enterprises to desert city center operating locations in favor of exurban sites. With growing frequency, selection of new sites appears to be heavily influenced by proximity of air transportation facilities. Growing legions of economic, cultural and community planning authorities are recognizing that the obvious means to reverse this trend is to bring the airport back to a convenient location near civic centers.

In predicting a coming revolution in aviation technology recently, FAA Administrator Najeeb E. Halaby said, "It may well be that the only possible solution to the urban transportation problem will be an aviation solution. There will be great strides in normal intercity operations and in city center to city center air transport.

"In our developing complex of urban communities, new air vehicles will not serve to provide effective air transportation without an appropriate system of airports. . . . We cannot afford to sit back and watch the effectiveness of our air transportation system being strangled by inadequate airport access."

David D. Thomas, FAA Assistant Administrator for Programs, has revealed that the FAA's latest National Airport Plan, released in late September, calls for development of 727 new landing facilities and improvement of 2,537 existing ones over the next five years if the United States is to meet the continuing growth and demands of civil aviation.

Significantly, 579 of those new airports would be for general aviation use exclusively. "This reflects increasing—and sometimes critical—need for these facilities in both metropolitan and small communities," Thomas said. "Since the end of World War II we have been steadily losing general aviation airports in our large metropolitan areas where they are critically needed to drain off light aircraft traffic from the major air terminals. . . . Here in Washington we saw 10 area airports go by the boards in a 10-year period."

Economic benefits that may accrue to the District if Bolling becomes a general aviation facility are probably more far-reaching, flexible and substantial than those which could be expected through a fixed residential area tax structure. Various studies and surveys have proven that close-in general aviation airports in other metropolitan areas have introduced new wealth and business enterprises into the community. As reported in the AOPA Airport Letter some time ago, one such close-in facility, the Riverside, Calif., Municipal Airport, has attracted nationwide attention because it represents the trend in public interest thinking about airports. Located and designed to provide close-to-town facilities for private and business aircraft, Riverside Municipal has made the area especially attractive for desirable industry.

A study made at a close-in general aviation airport at a Midwest city indicated that each typical transient business plane flight left behind it $230.20 in financial benefits to the community after a 48-hour stopover. Of this, $113.70 was spent at the airport for services, and $116.50 was spent in the city for room, meals, and other services or incidentals. Computed on a similar basis, it is conceivable that Bolling as a general aviation airport could introduce, conservatively, $500,000 of new money into the District annually through aircraft operations alone.

The impact on the entire country of the growing use of private and business aircraft was pointed up recently by Senator William Proxmire in an address made from the floor of the U.S. Senate. Speaking out against over-regulation of general aviation, he linked the growth of that activity to many aspects of the nation's economy and cultural development.

"Some observations about general aviation are worth sharing," Senator Proxmire told his colleagues. "It has greatly expanded our horizons for recreation, commerce and government for a relatively small but potent and influential number of people, and can do so for many more. It has sharply increased the pace of business and political competition. By reducing the unproductive travel time of costly personnel, the airplane, particularly general aviation, has acted as a labor creator rather than as a labor saver. By making it possible to do more things the airplane has forced people to do more to keep ahead of the competition."

This holds true, however, only if general aviation facilities are conveniently located. At least three examples to back this up are provided by close-in metropolitan airfields: Mud Island Airport is just 60 seconds by ferry from downtown Memphis; Chicago Meigs Field and Cleveland's Lakefront Airport are both within walking distance of business districts, have fostered drastic upsurges of aircraft usage in those cities.

At the National Aviation System Symposium and the 1964 Annual Assembly Meeting of the Radio Technical Commission for Aeronautics, both held in Washington, D.C., Sept. 30 and Oct. 1, a constantly recurring theme was the necessity to recognize and properly plan for the dynamic growth of general aviation. It does not follow that obliteration of the excellent facilities for general aviation that exist at Bolling would contribute to orderly planning. Preservation of that field not only would be a benefit to the nation's capital; it would prove a boon to the entire country and could set a precedent that might be followed by many other metropolitan areas.

As long as there is hope, AOPA will fight for the preservation of Bolling for general aviation. Its members will be encouraged to make known their views to the Association, to FAA and to their elected representatives to Congress. ●

Flight

A crippled transport, two engines dead, skims the waves of the Pacific Ocean for a thousand miles before limping into a safe landing at San Francisco. A jet fighter flames out on final approach. Too low for a successful ejection, the pilot points his nose down briefly, then levels out just above the grass and somehow manages to stretch his glide far enough to plant the heavy bird on the first inches of the runway. A private pilot pulls his heavily loaded lightplane onto the thin, hot air of a high altitude field, but the ship refuses to climb and mushes with a sickening crash into the trees at the end of the field.

In each of these cases the airplane was experiencing one of the effects of that often-mentioned, seldom-understood phenomenon of "ground effect." Just what is ground effect? Is it a layer of air near the ground that has different characteristics from other air? Is it a cushion of high-density air that is built up under the wings as we approach the ground?

No, in spite of the hangar-flying stories and theories, it's neither of these. Actually, the term "ground effect" can be applied to a number of somewhat different conditions. However, they are all concerned with the fact that, when an airplane flies close to the ground, the air is forced to flow around the plane, and especially the wing, in a different manner from when the plane is high above the ground. This varied airflow, and the different forces it produces on the aircraft, cause the conditions we call ground effect.

The most noticeable ground effects, and the ones that will be discussed here, are a result of the reduction of the intensity of the wing-tip vortices when the wing is close to the ground. Any time a wing produces lift, the air along the lower surface of the wing has a greater pressure than the air along the upper surface. At each wing tip, the air from the lower surface comes up around the tip and mixes with the air on the upper surface, and a wing tip vortex is formed, as shown in Figure 1a.

A vortex has been defined as a means for converting useful energy into completely useless energy. A wing-tip vortex is a manifestation of this wasted energy, or, in slightly different terms, it represents a form of airplane drag—the induced drag. The induced drag of any airplane at any flight condition is

Effects Of Ground Effect

by F. ROBERT MORRISON • AOPA 131907

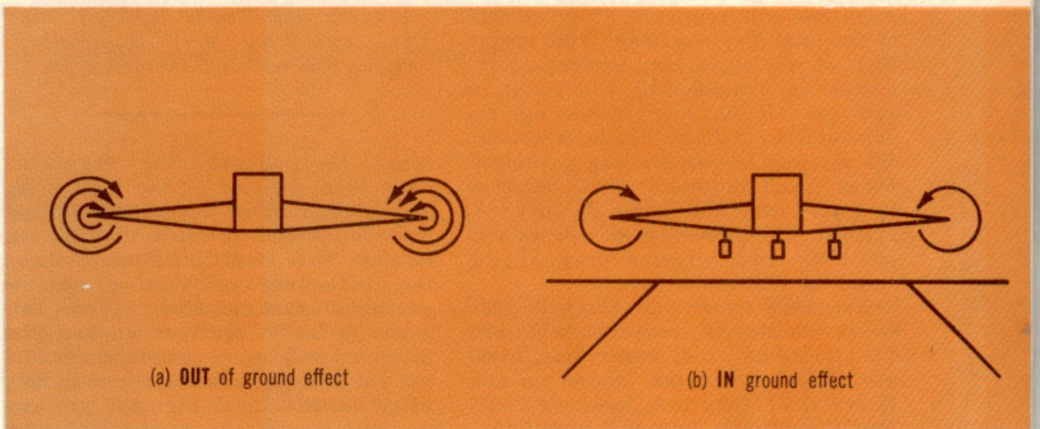
Whether 'ground effect,' and its accompanying reduced drag, is friend or foe depends upon pilot's understanding of the principle and how well he uses it

directly related to the intensity of its wing-tip vortices. The intensity of the tip vortices in turn depends upon the pressure difference which exists between the upper and lower surfaces of the wing—in other words, the lift.

But what does this have to do with ground effect? Just this. As our wing passes through the air, it affects a lot more air than most of us give it credit for. Actually, just as a pebble dropped into a mountain brook creates a ripple that is felt (if ever so slightly) on the farthest beach in the Pacific, so does our moving wing affect the entire air mass surrounding the earth. (Again, ever so slightly.) However, in a practical sense, we can consider our wing to create a significant effect on the air for a distance of about one-half wing span above and one-half wing span below the wing. As the wing approaches the ground, the ground begins to make its influence felt on the airflow around the wing, including the wing-tip vortices. The free swirl of the air forming the wing-tip vortices is restrained more and more as the influence of the ground changes the air flow pattern around the wing. (See Figure 1b.)

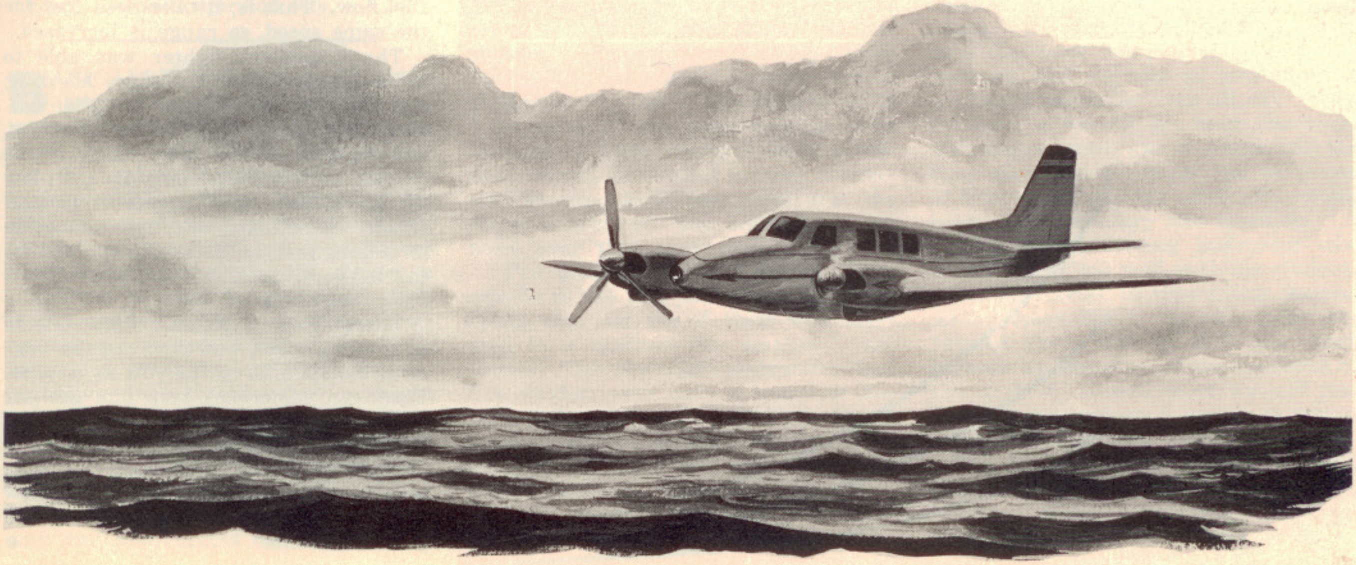
Since the intensity of the wing-tip vortices is reduced, so is the induced drag reduced. This is probably the most important result of ground effect. For a given speed, any airplane—or helicopter, for that matter—will have less drag when it is close to the ground. This, of course, will affect the performance.

FIGURE 1. Ground effect as it affects wing-tip vortices



How much less drag? Well, it can be considerably less, or it can be only slightly less, depending on the flight conditions. Since ground effect reduces only the induced part of the total airplane drag, let's see how much induced drag the airplane will have. Then we can relate this to total drag, which is really what our airplane will recognize.

We won't go into the aerodynamic analysis here, but it can be shown that the reduction in induced drag depends



on how high the wing is above the ground, expressed in terms of the wing span. Checking some representative points, we would find that, at a wing height equal to one-half wing span above the surface of the ground, the induced portion of our drag is reduced by about 8%. At a height equal to one-fourth span, the induced drag is reduced about 50%.

But induced drag is just one part of the total airplane drag. Parasite drag is the other part. Unfortunately, there is no fixed proportion between these two kinds of drag. The proportions depend very greatly on the speed at which our airplane is flying. However, there is one very convenient landmark that we can utilize.

When any airplane is flying at the indicated airspeed at which it obtains its best glide ratio (it doesn't actually have to be gliding, only flying at the same speed), the parasite drag and the induced drag will be exactly equal. Each one will represent just one-half of the total airplane drag. This means that, *at this speed*, any percentage reduction in induced drag will result in just one-half that much percentage reduction in total drag. For instance, our 8% decrease in induced drag mentioned above would represent a 4% decrease in total drag. In Figure 2, Curve A, labelled "Best Glide Speed," shows this effect on total airplane drag at the speed for best glide ratio.

At speeds faster than the best glide speed, the induced drag represents less than one-half the total drag, and ground effect becomes less important. Curve C of Figure 2, labelled "125% Best Glide Speed," shows the total drag reduction due to ground effect at a speed 25% greater than Curve A. This would represent an indicated airspeed somewhere in the neighborhood of a normal cruising speed at altitude, depending on the individual airplane.

At speeds less than the best glide speed, the induced drag represents more than one-half of the total drag, and ground effect is correspondingly more important. Curve B of Figure 2, labelled "75% Best Glide Speed," shows the total drag reduction caused by ground effect at this lower speed. This would typically represent a speed just after takeoff, or a speed you would use for clearing obstacles immediately after takeoff. From Figure 2, you can see that ground effect can make a big difference in the airplane's drag, especially at the low-speed end of the speed range. At higher speeds, where induced drag is relatively unimportant, ground effect is also relatively unimportant.

As an example of ground effect, consider a typical lightplane with a best glide speed of 80 knots and a wing span of 36 feet. If this airplane climbs out after takeoff at a speed of 80 knots, let's see how ground effect will work on it. Referring to Figure 2, Curve A, we see that, as the wing gets to a height of nine feet above the runway (one-fourth wingspan), it will have about 12% less drag than at altitude. By the time the wing is 18 feet above the ground (one-half wingspan), this drag saving has dwindled to 4% and the climbing ability has dwindled as well, probably more than the drag has increased.

If the speed is slower, the induced drag is higher, and the *differences* in drag as the wing climbs out of ground effect are even more noticeable. At a climbing speed of 60 knots, or 75% of best glide speed, referring to Curve B of Figure 2, the 9-foot wing height gives a drag reduction of over 18%, while the 18-foot wing height gives only about 6% drag reduction. Or, stated a little differently, the airplane, in climbing at a speed of 60 knots from a height of 9 feet to 18 feet, experiences a drag *increase* of 12%. Under marginal climbing conditions, such as high altitude, hot day or heavy weight operations, the airplane acts as though it has hit a ceiling just a few feet off the ground. This effect has accounted for a number of accidents like the ones described in the opening paragraph. Several of the early attempts at trans-ocean flights met with disaster when the overloaded planes were unable to climb out of the favorable low-drag ground effect. Many "hot rod" takeoffs have come to grief for the same reason, when the airplane was unable to sustain its spectacular climb angle after losing the benefits of ground effect.

In the case of the crippled transport, the drag reduction resulting from ground (in this case, water) effect can be sufficient to allow the airplane to maintain altitude just above the wave tops and to stretch the range far enough to reach a safe port. At a given speed, any percentage reduction in drag will result in an equal percentage reduction in the power required to fly, and there will be a corresponding reduction in fuel flow. That is, it takes less fuel for the same speed, so range is increased.

The flamed-out fighter was able to utilize ground effect to reduce his drag and therefore to increase his glide distance enough to make a safe landing. Anyone can do the same thing if the terrain will allow him to get low enough to gain the benefits of ground effect. Sometimes this type of glide stretching is done inadvertantly, and we call it "floating," but it's still just plain old ground effect.

These are not the only flight effects of ground effect, but they are the ones of primary interest to you as a pilot. They can sometimes help you get out of trouble and sometimes help you get into trouble. Whether "Old Man Ground Effect" turns out to be your friend or your adversary depends simply on how well you understand him and how well you utilize him. ●

THE AUTHOR

F. Robert Morrison, author of "Flight Effects Of Ground Effect," is an engineering lecturer at the University of Southern California at Los Angeles. He is a member of the Aerospace Safety Division staff. He describes his duties at USC to The PILOT *this way: "My job . . . is to teach interesting, useful material to pilots in order to enable them to do a better, safer job of flying. The material I cover comes under the heading of the practical application of aeronautical engineering principles to the safe operation of aircraft. The emphasis is on the practical application. I am a pilot and all of my students are pilots." Morrison has been an AOPA member since 1956. He received a degree in aeronautical engineering at West Virginia University and worked as an engineer for North American Aviation and Temco Aircraft. He does consulting work in aviation safety and accident investigation.*

FIGURE 2. Drag reduction and best glide speed