THE PHYSICS OF FLIGHT

By Dave Pickenpaugh

Chapter III - Tip Vortices and Ground Effect

When discussing wings and airfoils, we have a tendency to think two-dimensionally about the airflow across the curve of the airfoil. The airfoil profile has a great deal to do with the performance of the wing, but it takes the third dimension -- wing span -- to complete the analysis.

Remember that an airfoil creates a pressure differential between the top and bottom surfaces of the wing. The result is a potential for inducing air flow from the high pressure area to the lower pressure. Along the span of the wing this tendency is responsible for generating lift. At the wing tips there is nothing to block this air flow, resulting in air spiraling about the wing tips.

This spiral of air at the end of the wing is called a wingtip vortex. It is most prevalent at slow speeds and high angles of attack, such as when an airplane is taking off or landing. Since the plane is moving forward the vortex trails behind the wing, and therefore is also referred to as a trailing vortex. One emanates from each wing tip in a counter-rotating fashion. In most situations the vortices rotate from the bottom of the wing to the top.

Pilots of full-scale aircraft also refer to the vortices as wake turbulence, and is greatest with heavy aircraft. Heavy aircraft require more lift which results in a greater pressure differential between the top and bottom surfaces of the wing. The greater pressure differential means stronger vortices from each wing tip.

Vortices are generated by all airplanes -- even our RC planes -- but are strongest with large heavy airplanes. In full scale aircraft, flying in the vortices from another airplane can be extremely dangerous. I spoke with one pilot who was in a Cessna 172 when passing through the turbulence from a heavy jet. The pilot was taking off and was at a very low altitude when the plane suddenly rolled about 90 degrees and shook violently. It was a close call but he managed to recover.

For our RC airplanes, tip vortices will rarely be a problem during take off and landing. They do play a role in the efficiency of the wing and the amount of lift it can generate. The tip vortices exerts a downward motion to the air leaving the trailing edge of the wing. This downward push is called down-wash and affects the direction of the air movement across the wing. Remembering that lift acts perpendicular to the relative wind, down-wash has a tendency to angle the lifting force slightly backward. Since the lift force is angled backward, part of the lifting force acts in a rearward direction. This means that effective lift is slightly reduced, and a greater angle of attack is needed to generate sufficient lift. The rearward acting component of lift is called induced drag.

The efficiency of a wing with a short span is affected more by tip vortices than a longer wing. Hence, the longer span reduces the angle of attack needed to generate a given amount of lift. This reduces the drag associated with higher angles of attack and makes wings more efficient.

How does all of this relate to ground effect? You have probably heard pilots of full-scale airplanes talk about how a plane wants to float as it nears the ground. The disruption of the tip vortices by contact with the ground reduces the down-wash angle, and therefore reduces the rearward angling of the lifting force making the wing more efficient by decreasing induced drag and increasing lift. Obviously, high-wing planes will not see as much ground effect as low-wing planes.

Endplates and winglets have been used on airplanes to minimize tip vortices even when out of ground effect. There is a trade off in that total drag at all speeds is increased by the added device even though performance may be increased at slow speeds and high angles of attack.

Obviously, most of us in RC flying will not experience many of the benefits or detriments of tip vortices or ground effect. However, the biggest area to watch is in landing on short fields. If your plane is heavy, has a low-wing design, and the wing is short, watch out on those landings. You may find out that the plane wants to float when it gets close to the ground. At one span-length above the ground you will not notice any difference in the performance of the airplane. When the plane is about 3/10 of a span-length there is a 20% reduction in induced drag. This means the wing lifts more efficiently and less angle of attack is needed. Even pushing the elevator stick forward does not seem to lower the plane to the ground, and ground speed may actually increase. When at 1/10 of a span-length above the ground, the induced drag on the plane is reduced approximately 50 percent! As discussed above, lower aspect ratio wings will be affected much more than long slender wings.

Be on the lookout for ground effect when landing, but also on take off. That big war bird with the short stubby wings mounted in a low-wing configuration can also experience ground effect on take off. It may be possible to break ground on take off only to find that there is insufficient lift to leave the zone of ground effect. Some pilots of full-scale airplanes have gotten themselves in tight situations where they were able to break ground, but then flew for miles before being able to overcome ground effect.