Vortex Characteristics

The wake generated behind an aircraft has two sources. The first is turbulence caused by profile drag and engine thrust—a disorganized motion that diminishes to a harmless level several wingspans behind the aircraft. The second source is the vortex pair. The vortices are highly organized and decay only slowly, persisting for miles behind the generating aircraft.

The FAA publications do a good job of describing the typical behaviors of aircraft vortex wakes, and in describing the appropriate avoidance techniques for aircraft following behind. But the graphics used (often a widening spiral) tend to give a misleading impression of vortex structure and therefore of aircraft response. We’ll address that here. In addition, in ground school you’ll see wind tunnel films showing how the vortex rolls up around a wingtip, and also videos from NASA that show vortex structure and encounter dynamics downstream. The NASA videos reveal how mobile the vortex core is in turbulent conditions, and how abruptly it can change position in response to penetration by a large aircraft.

Figure 1 shows vortex structure in terms of the tangential velocity at increasing distance from the core.
Core size depends on vortex intensity. The cores from transport aircraft have been estimated to be anywhere from two to five feet in diameter. Core size is believed to be of minor importance in a vortex encounter, as long as the ratio of the wingspan of the follower aircraft to core diameter is large. The radius of influence of the vortex flow field surrounding the core is typically twenty-five to fifty feet, according to the FAA.

The vortex pair descends behind the generating aircraft because of the mutual induction between the two fields of circulation—each vortex pushes the other down. The rate of descent depends directly on vortex strength, and on wingspan: for a given vortex strength, the greater the wingspan the slower the descent. It also depends on temperature stratification in the atmosphere (a descending vortex pair heats up due to adiabatic compression and becomes buoyant). Crosswinds can reduce sink rates, sometimes more on one vortex than the other, causing the pair to tilt.

Vortices formed close to the runway have been observed to “bounce” back to higher altitude, indicating that the recommendation given in the *Aeronautical Information Manual* that pilots fly above the glide path of the preceding aircraft may not always ensure protection.

Circulation is a measure of the angular momentum of the air in the surrounding flow field, and defines the strength of a vortex. That strength is directly proportional to the weight of the generating aircraft and inversely proportional to its velocity and wingspan (speed and span reduce the vortex).

Size and strength of the flow field determine the risk to the follower. A hazardous situation can occur when the leading aircraft is landing at its maximum landing weight, and the follower aircraft is operating at minimum weight—and therefore with minimum roll inertia.

When the follower aircraft has a large span, the encounter forces are distributed over a greater lateral distance. The induced rolling moments build up more gradually and are less intense relative to the aircraft’s aileron control power.

Studies have shown that a follower aircraft with the same span as the generating aircraft will typically have enough maximum aileron control power to handle wake-induced rolling moments. Pilots, however, consider the need for maximum control inputs as unacceptably hazardous.
Simulations, wind tunnel studies, and in-flight research demonstrate that penetrating a vortex core is unlikely. Depending on the follower aircraft’s intercept angle, speed, and inertia, the flow field tends to roll the aircraft away from the vortex. In a more serious encounter, the aircraft can be carried over the core and through the downwash between the generator’s wingtips (Figure 3, right).

Because penetrating, let alone staying within, the vortex core is unlikely, pilots shouldn’t conclude from an initial, rapid roll acceleration (or from upset training) that continuing to roll the aircraft through 360 degrees in the vortex direction constitutes an automatic recovery procedure. Although that type of recovery could become necessary when a small aircraft follows a heavy one, the probability is low that a roll excursion will go that far.

Pilots often inadvertently reinforce the rolling moments generated by a vortex encounter. For example, an aircraft entering the right-hand vortex from the outside will experience an abrupt rolling moment to the right, as in Figure 3. Responding with left aileron will reinforce the vortex-induced rolling moment once the left wing passes the core and enters the downwash area.

The interaction between the vortex flow field and the aircraft’s vertical tail produces yawing moments that often result in Dutch roll oscillation, especially with swept-wing aircraft. Pilots trying to settle the aircraft down tend to get their control inputs out of phase and instead amplify the oscillation.

According to the Flight Safety Foundation, the especially bad news is that more than two-thirds of all wake vortex accidents and reported incidents happen over the runway threshold.
Vortex Wake Turbulence