Aircraft Wake Turbulence Avoidance

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Theme

AIRCRAFT trailing vortex systems are made up of two counter-rotating cylindrical air masses, about a wing span apart, extending aft along the flight path. Vortex systems of large aircraft contain winds which can be hazardous to other aircraft encountering them in flight. The vortices are difficult to detect behind the large aircraft and persist for quite some time after generation.

Results of analytical studies and flight tests are used to describe the formation, severity, and the spatial extent of trailing vortices. This information is then used to outline procedures, for ready application by pilots and others concerned with the flow of traffic, on how best to avoid the dangerous portions of the wake during flight operations.

Contents

Tangential velocities within a vortex system close behind a large heavy aircraft, as the C-5A transport, can be on the order of ±3600 ft/min up to 1½ miles astern, or 30 sec after aircraft passage and vary directly with the aircraft weight and inversely with aircraft velocity. Other elements influencing vortex system behavior, more difficult to assess than the effects of aircraft speed and weight, are changes in flight path, air density, wind intensity, turbulence, precipitation, and ground proximity and roughness.

A trailing vortex system and the velocity distribution perpendicular to a line through the vortex centers some distance behind the generating airplane are illustrated in Fig. 1. Upwash and downwash velocities are apparent. Different hazard potentials to aircraft encountering these velocities are shown. An aircraft penetrating the core of a vortex (1) would experience imposed rolling moments. An aircraft subject to the downwash (2) would have to contend with a loss in rate of climb or an increase in rate of descent. If the penetrating aircraft approaches perpendicular to the vortex system, as along a line through the vortex centers (3) structural load factors would be the principal concern and, in addition, a bumpy ride would surely result.

In addition, there is a more subtle hazard related to pilot startle effect. Often vortex encounters are most pronounced when the atmosphere is well behaved and the pilot is experiencing smooth flight. Available reaction time to recover from vortex induced upsets near the ground is already brief and any unnerving effect delaying countermaneuvers would add to the problem of recovery.

Vortices have an inherent characteristic to move downward when formed. The downward movement is influenced by the wind, the increased air density encountered, and the proximity of the ground. The wake locations measured behind the C-5A aircraft for several test runs at an altitude of about 12,000 ft are given in Fig. 2 by the circled points. The vertical displacement of the wake tends to level off about 1000 ft below the flight path. The wake remained intact for distances exceeding 10 naut miles behind the C-5A, approximately 3 min after aircraft passage.

The roll responses of three aircraft (DC-9, Cessna 210, Lear Jet) on encountering the C-5A wake at various distances astern were recorded. Despite the best efforts of the pilot, bank angles exceeding 30° were imposed, up to separation distances of about 8 miles and a time lapse of 2.7 min. Obviously upsets of this type could be hazardous, especially in holding patterns, during approach to landing, and shortly after takeoff. Pilots could possibly encounter large load factors, bank angles, and roll rates in the shaded area of Fig. 2. The lateral displacement envelope shown in the figure accounts for drift of the vortices under crosswind conditions. An aircraft penetrating the shaded areas would not necessarily encounter a vortex because of their respective locations and because atmospheric turbulence and other factors can cause attenuation of vortex intensity, but pilots should avoid this air space by staying either above the flight path of the large aircraft or at least 1000 ft below. Of course, time spacing and distance separation of 3 min and up to 10 miles, respectively, of aircraft behind the large aircraft would be adequate to avoid dangerous encounters.

Vortex system movement near the ground is influenced by two major factors, the lateral spread inherent in the system and wind drift. The vortices settle to within about a wing semispan of the ground. Calculations of vortex movement for wind directions of zero degrees to 90° and from the port and from the starboard for time periods of significant vortex velocities results in a family of curves. An envelope about

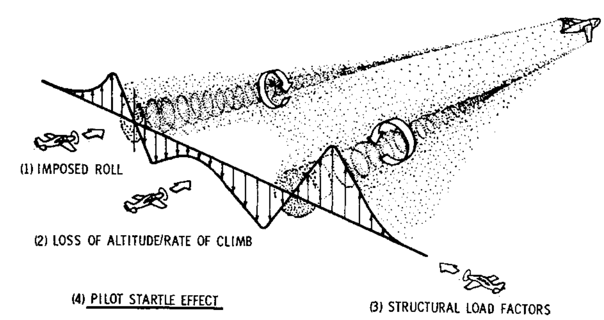

Fig. 1 Hazard potentials of trailing vortices.

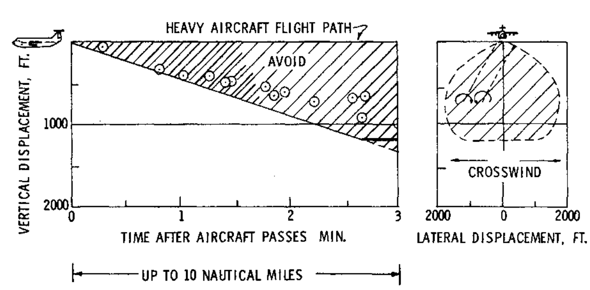

Fig. 2 Suggested envelope of vortex location for operational use (no ground effect).

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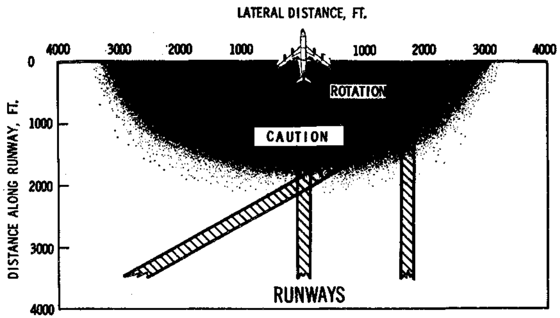

Fig. 3 Envelope of vortex-system movement near the ground.

this family of curves is shown by the shaded area of Fig. 3 and sets the bounds of vortex travel, within which vortex velocities could be of concern to following aircraft.

In general, an aircraft can avoid a possible encounter with the wake by lifting off 3000 ft short of the rotation point of the preceding heavy aircraft. Following takeoff it would be to the light plane pilot's advantage to remain on the upwind side and above the flight path of the larger aircraft. Pilots should take special care if the takeoff roll is started at points along the runway, as at an intersecting runway or taxiway, where liftoff can occur nearer than 3000 ft to the rotation point of the larger aircraft.

Figure 3 shows that the vortices might drift to runways other than the one used by the larger aircraft. Therefore pilots planning to take off on parallel or intersecting runways should consider the possibility of a vortex hazard and plan accordingly.

The envelope of Fig. 3 is also applicable to approach and touchdown procedures. The rotation point noted in the figure can be considered the touchdown point for this application. Under some landing conditions, with a small tail wind component, the vortices can drift 500 ft down the runway following touchdown of the large aircraft under the most adverse condition. In general, light aircraft pilots should plan to touch down 2500 ft beyond the touchdown point of the larger aircraft. As an example, if a large aircraft touches down 1500 ft from the threshold, the light aircraft should land 2500 ft beyond or at about the 4000 foot marker to avoid a possible vortex encounter.

It appears that these hazards could be minimized through pilot application of the vortex system envelope to airfields, using readily available information during preflight planning exercises.

A comprehensive NASA research effort is underway to improve the description of aircraft trailing vortex formation, persistence, and whereabouts. Other studies are aimed at the development of a concept either to discourage formation of intense trailing vortices or to induce early dissipation of the dangerous wake.