



U.S. Department
of Transportation

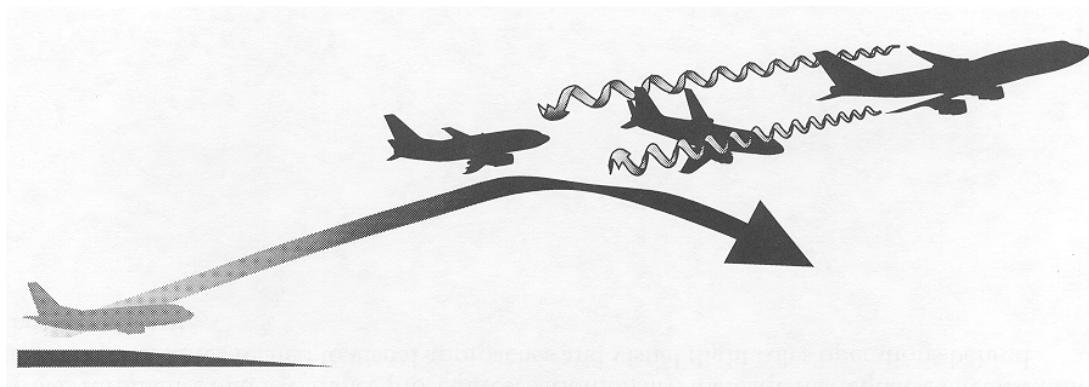
**Federal Aviation
Administration**

Advisory Circular

Subject: AIRCRAFT WAKE
TURBULENCE

Date: 02/20/02
Initiated by: AFS-430

AC No.: 90-23F
Change:



- 1. PURPOSE.** This advisory circular (AC) is intended to alert pilots to the hazards of aircraft wake turbulence and recommends related operational procedures.
- 2. CANCELLATION.** AC 90-23E, Aircraft Wake Turbulence, dated October 1, 1991, is canceled.
- 3. INTRODUCTION.** Every aircraft in flight generates a wake. Historically, when pilots encountered this wake the disturbance was attributed to "prop wash." It is known, however, that this disturbance is caused by a pair of counter-rotating vortices trailing from the wing-tips. The vortices from large aircraft pose problems to encountering aircraft. For instance, the wake of these aircraft can impose rolling moments exceeding the control authority of the encountering aircraft. Further, turbulence generated within the vortices encountered at close range can damage aircraft components and equipment and cause personal injuries. The pilot must learn to envision the location of the vortex wake generated by larger (transport category) aircraft and adjust his/her flight path accordingly.
- 4. VORTEX GENERATION.** Lift is generated by the creation of a pressure differential over the wing surfaces. The lowest pressure occurs over the upper wing surface and the highest pressure under the wing. This pressure differential triggers the rollup of the airflow aft of the wing resulting in

swirling air masses trailing downstream of the wing-tips. After the rollup is completed, the wake consists of two counterrotating cylindrical vortices (see figure 1). Most of the energy is within a few feet of the center of each vortex, but pilots should avoid a region within about 100 feet of the vortex core.

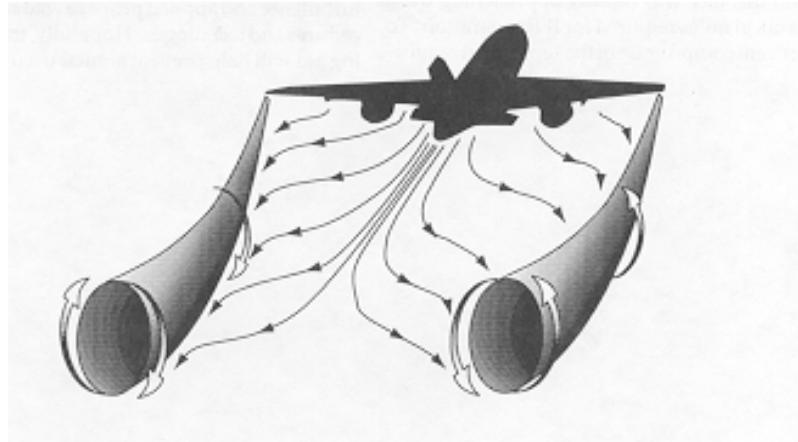


FIGURE 1. THE ROLLING UP PROCESS

5. VORTEX STRENGTH. The strength of the vortex is governed by the weight, speed, and shape of the wing of the generating aircraft. The vortex characteristics of any given aircraft can also be changed by extension of flaps or other wing configuring devices. However, as the basic factor is weight, the vortex strength increases proportionately with increase in aircraft operating weight. Peak vortex tangential speeds up to almost 300 feet per second have been recorded. The greatest vortex strength occurs when the generating aircraft is heavy-clean-slow.

6. INDUCED ROLL.

a. In rare instances, a wake encounter could cause in-flight structural damage of catastrophic proportions. However, the usual hazard is associated with induced rolling moments which can exceed the roll control capability of the encountering aircraft. In flight experiments, aircraft have been intentionally flown directly up trailing vortex cores of larger aircraft. It was shown that the capability of an aircraft to counteract the roll imposed by the wake vortex primarily depends on the wingspan and counter-control responsiveness of the encountering aircraft.

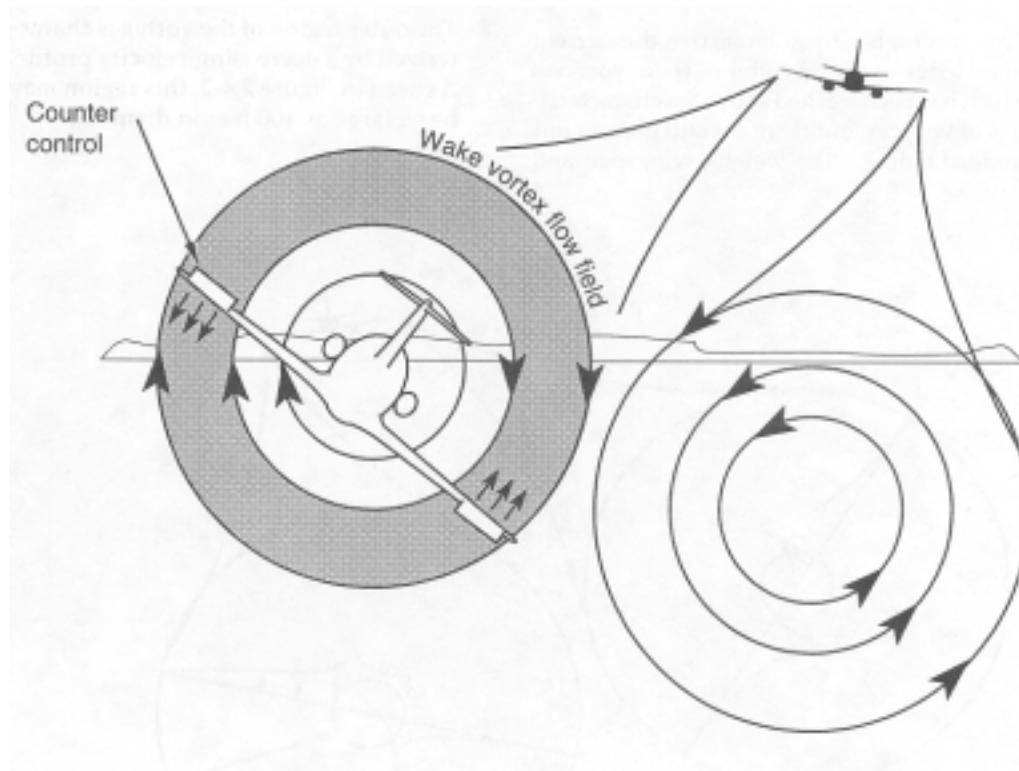


FIGURE 2. INDUCED ROLL

b. Counter-control is usually effective and induced roll minimal in cases where the wingspan and ailerons of the encountering aircraft extend beyond the rotational flow field of the vortex. It is more difficult for aircraft with short wingspans (relative to the vortex generating aircraft) to counter the imposed roll induced by vortex flow. Pilots of short-span aircraft, even of the high performance type, must be especially alert to vortex encounters. The wake of larger aircraft requires the respect of all pilots (see figures 2 and 3).

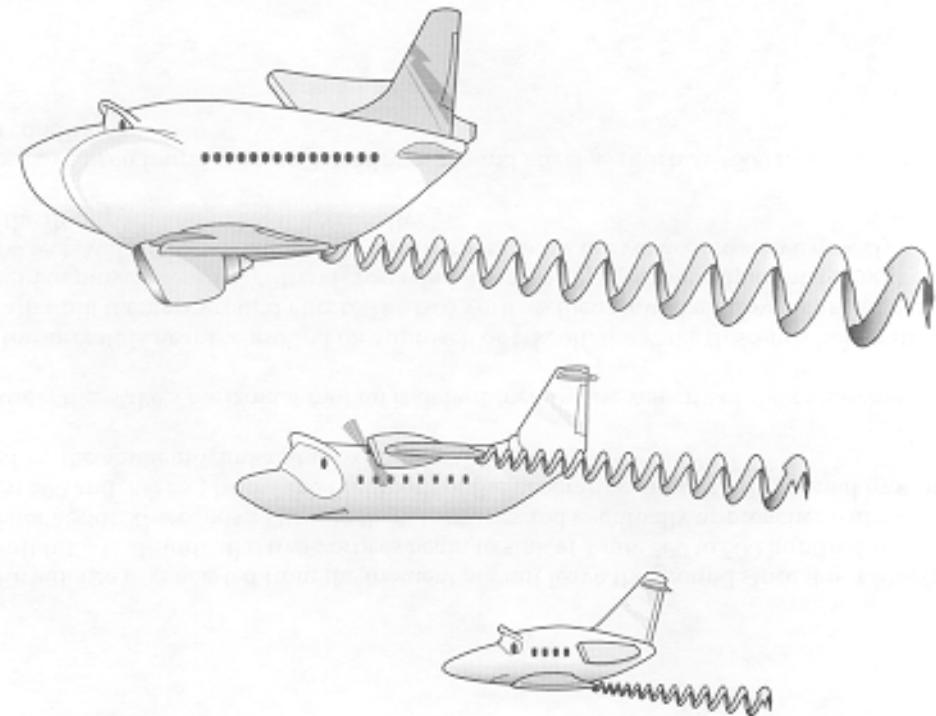


FIGURE 3. WAKE VS. AIRCRAFT WEIGHT

7. VORTEX BEHAVIOR. Trailing vortices have certain behavioral characteristics which can help pilots visualize the wake location and thereby take avoidance precautions.

- a. Vortices are generated from the moment aircraft leave the ground, since trailing vortices are a by-product of wing lift. Prior to takeoff or landing, pilots should note the rotation or touchdown point of the preceding aircraft (see figure 4).

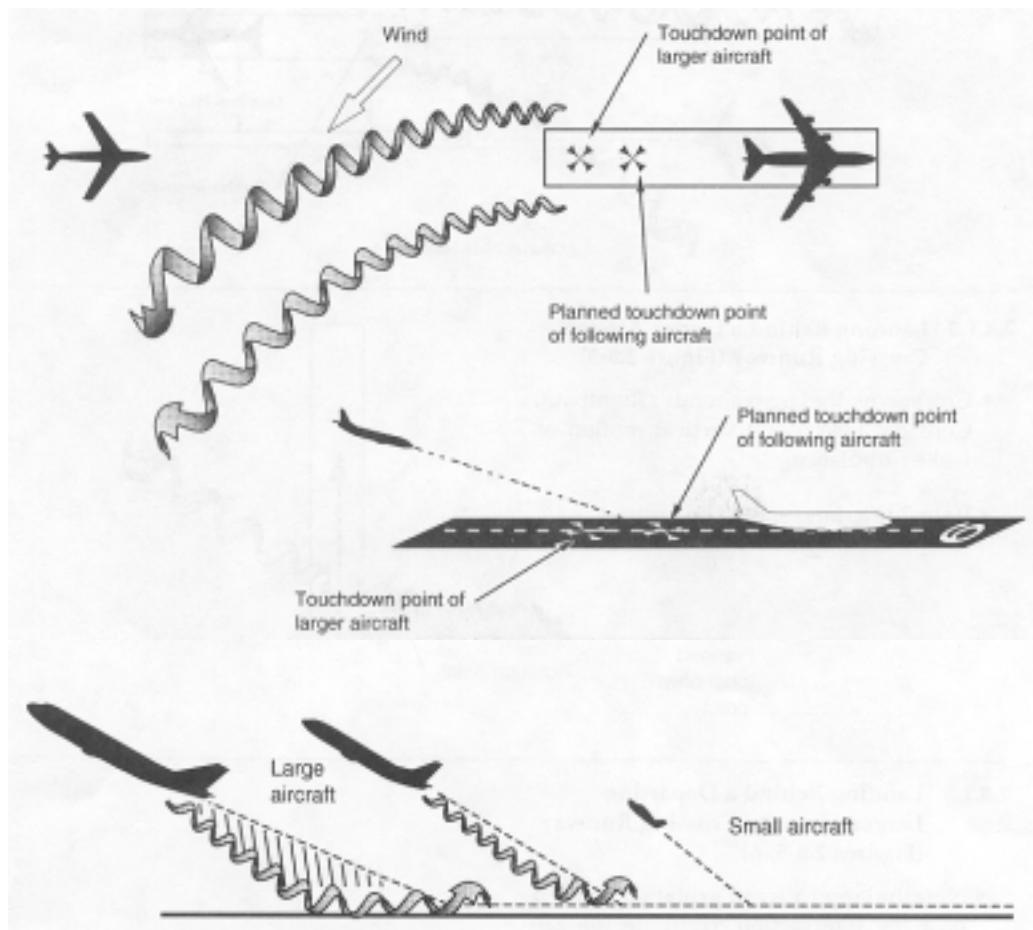


FIGURE 4. ROTATION AND TOUCHDOWN POINTS OF PRECEDING AIRCRAFT

b. The vortex circulation is outward, upward, and around the wing-tips when viewed from either ahead or behind the aircraft. Tests with large aircraft have shown that the vortices remain spaced a bit less than a wingspan apart, drifting with the wind at altitudes greater than a wingspan from the ground. In view of this, if persistent vortex turbulence is encountered, a slight change of altitude and lateral position (preferably upwind) will provide a flight path clear of the turbulence.

c. Flight tests have shown that the vortices from larger (transport category) aircraft sink at a rate of several hundred feet per minute, slowing their descent and diminishing in strength with time and distance behind the generating aircraft. Atmospheric turbulence hastens breakup. Pilots should fly at or above the preceding aircraft's flight path, altering course as necessary to avoid the area behind and below the generating aircraft. However, vertical separation of 1,000 feet may be considered safe (see figure 5).

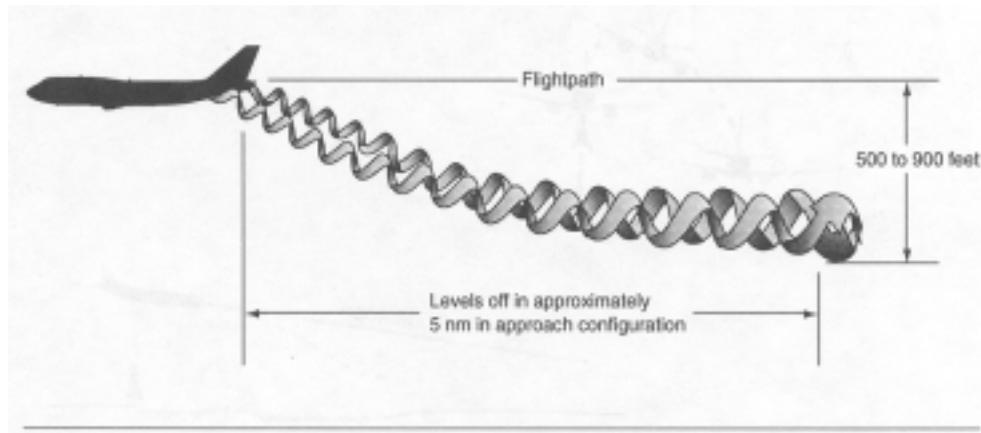


FIGURE 5. DESCENT OF VORTICES FROM LARGER AIRCRAFT

- d. When the vortices of larger aircraft sink close to the ground (within 100 to 200 feet), they tend to move laterally over the ground at a speed of 2 or 3 knots (see figure 6).

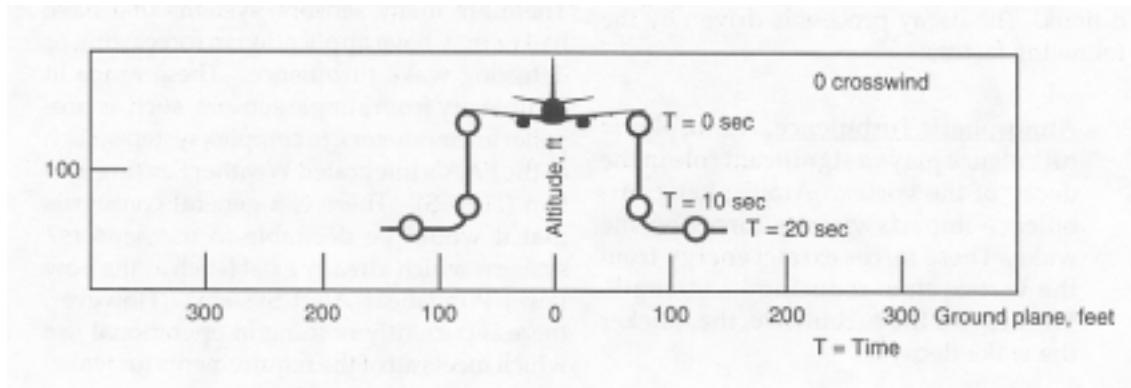


FIGURE 6. MOVEMENT OF VORTICES FROM LOW FLYING LARGE AIRCRAFT

- e. A crosswind will decrease the lateral movement of the upwind vortex and increase the movement of the downwind vortex (figure 7). Thus, a light wind with a cross-runway component of 1 to 5 knots (depending on conditions) could result in the upwind vortex remaining in the touchdown zone for a period of time and hasten the drift of the downwind vortex toward another runway. Similarly, a tailwind condition can move the vortices of the preceding aircraft forward into the touchdown zone. The light quartering tailwind requires maximum caution. Pilots should be alert to larger aircraft upwind from their approach and takeoff flight paths.

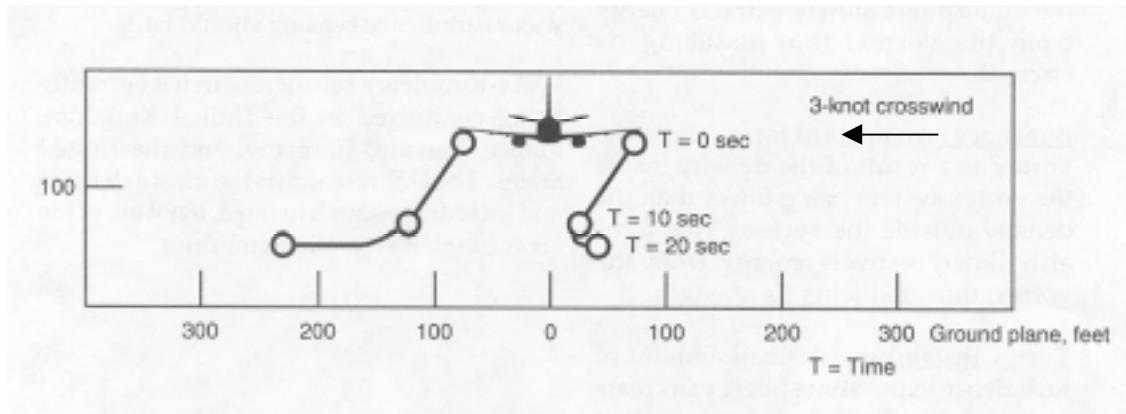


FIGURE 7. EFFECT OF 3-KNOT CROSSWIND ON VORTICES FROM LOW FLYING AIRCRAFT

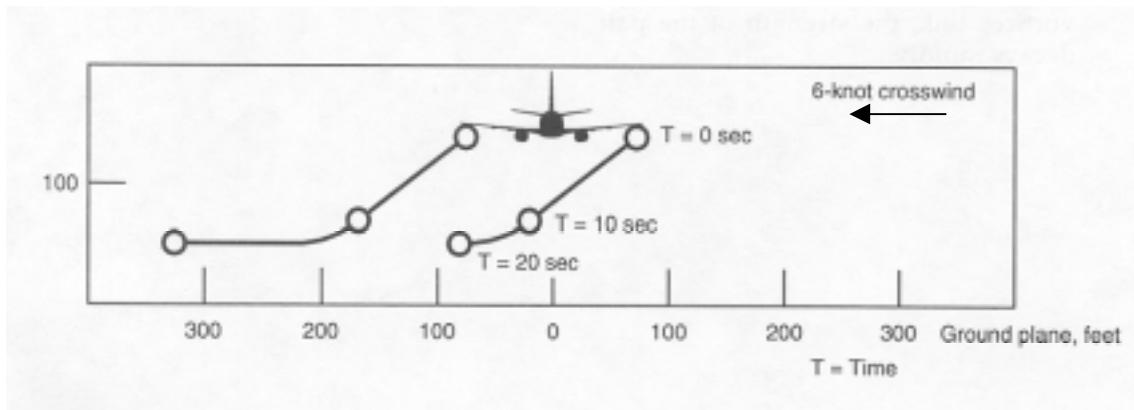


FIGURE 8. EFFECT OF 6-KNOT CROSSWIND ON VORTICES FROM LOW FLYING AIRCRAFT

8. OPERATIONAL PROBLEM AREAS.

a. A wake encounter is not necessarily hazardous. It can be one or more jolts with varying severity depending upon the direction of the encounter, weight of the generating aircraft, size of the encountering aircraft, distance from the generating aircraft, and point of vortex encounter. The probability of induced roll increases when the encountering aircraft's heading is generally aligned or parallel with the flight path of the generating aircraft. Avoid the area below and behind the generating aircraft, especially at low altitude where even a momentary wake encounter could be hazardous. Pilots should be particularly alert in calm wind conditions and maneuvering situations in the vicinity of the airport where the vortices could:

- (1) remain in the touchdown area,
- (2) drift from aircraft operating on a nearby runway,

- (3) sink into takeoff or landing path from crossing runway,
- (4) sink into the traffic patterns from other airport operations, or
- (5) sink into the flight path of aircraft operating under Visual Flight Rules (VFR) and at hemispheric altitudes 500 feet below.

b. Pilots of all aircraft should visualize the location of the vortex trail behind larger aircraft and use proper vortex avoidance procedures to achieve safe operation. It is equally important that pilots of larger aircraft plan or adjust their flight paths, whenever possible, to minimize vortex exposure to other aircraft.

9. VORTEX AVOIDANCE PROCEDURES. Under certain conditions, airport traffic controllers apply procedures for separating IFR aircraft. If a pilot accepts a clearance to visually follow a preceding aircraft, the pilot accepts responsibility for separation and wake turbulence avoidance. The controllers will also provide to VFR aircraft, with whom they are in communication and which in the tower's opinion may be adversely affected by wake turbulence from a larger aircraft, the position, altitude and direction of flight of larger aircraft followed by the phrase "CAUTION – WAKE TURBULENCE." After issuing the caution for wake turbulence, the airport traffic controllers generally do not provide additional information to the following aircraft unless the airport traffic controllers know the following aircraft is overtaking the preceding aircraft. WHETHER OR NOT A WARNING OR INFORMATION HAS BEEN GIVEN, HOWEVER, THE PILOT IS EXPECTED TO ADJUST AIRCRAFT OPERATIONS AND FLIGHT PATH AS NECESSARY TO PRECLUDE SERIOUS WAKE ENCOUNTERS. When any doubt exists about maintaining safe separation distances between aircraft to avoid wake turbulence, pilots should ask the control tower for updates on separation distance and aircraft groundspeed.

a. When landing behind a larger aircraft - same runway (figure 9) - stay at or above the larger aircraft's final approach flight path. Note touchdown point - land beyond it.

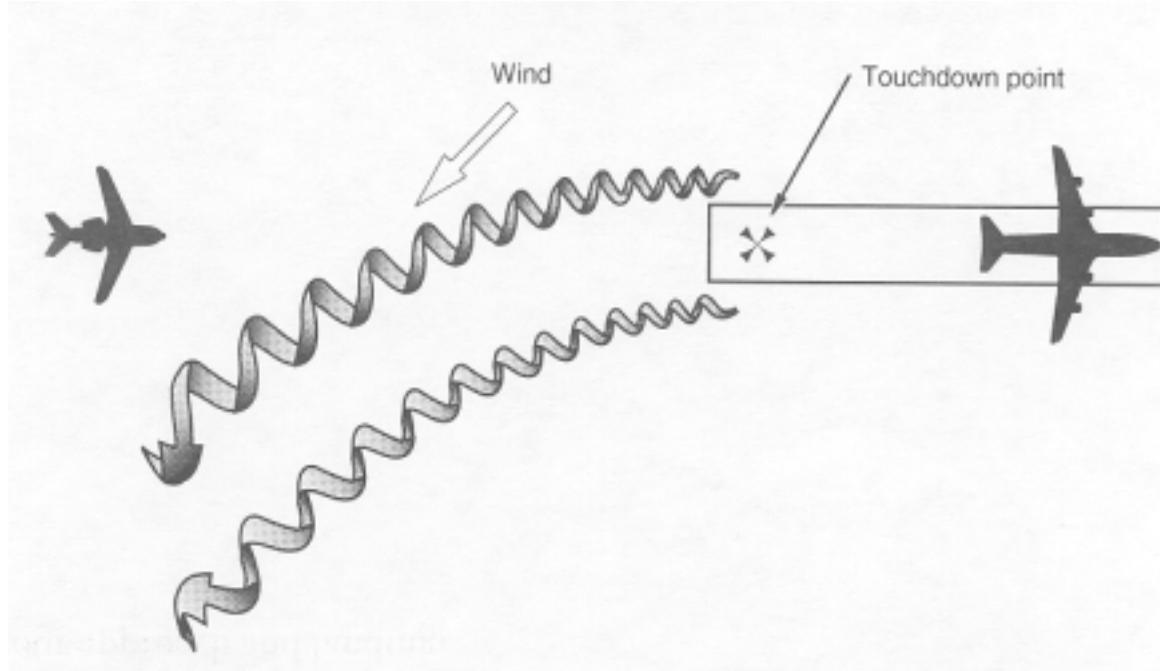


FIGURE 9. AVOIDANCE PROCEDURES LANDING BEHIND LARGER AIRCRAFT ON THE SAME RUNWAY

- b.** When landing behind a larger aircraft - when parallel runway is closer than 2,500 feet (figure 10) - consider possible vortex drift onto your runway. If you have visual contact with the larger aircraft landing on the parallel runway, whenever possible, stay at or above the larger aircraft's final approach flight path. Note its touchdown point.

Avoidance Procedures: Landing

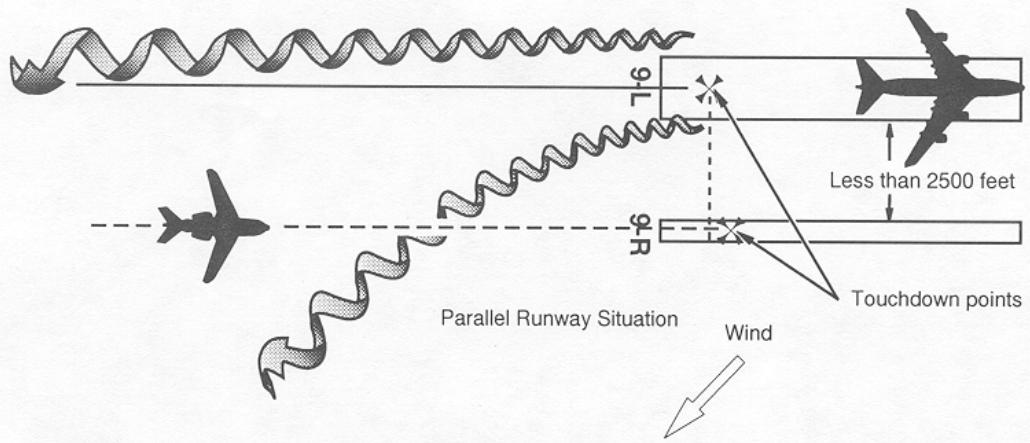
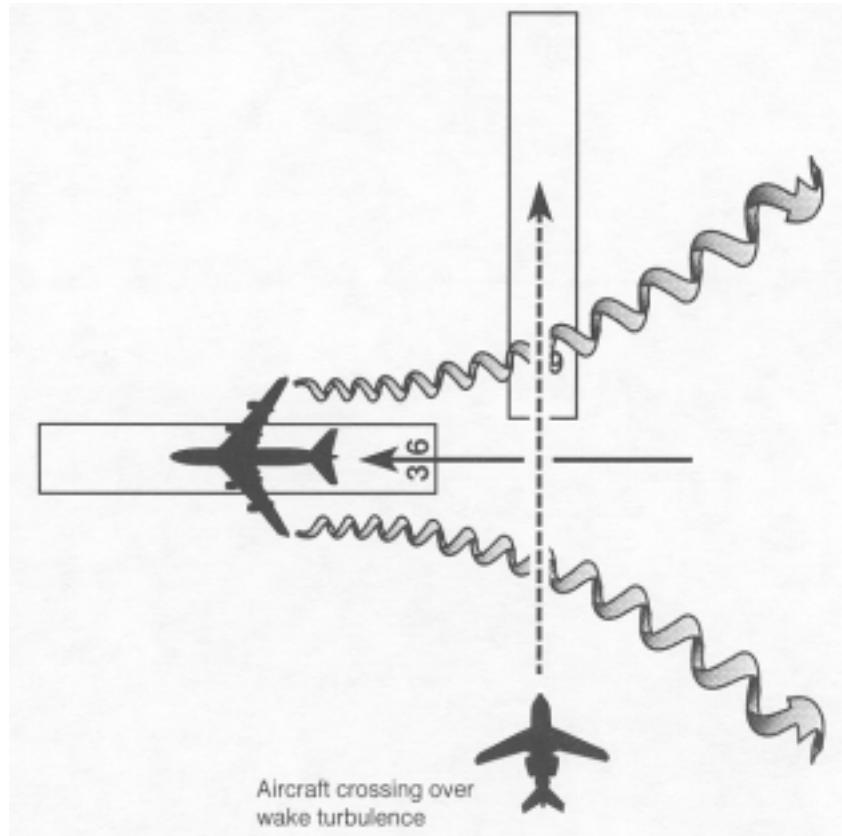


FIGURE 10. AVOIDANCE PROCEDURE LANDING ON PARALLEL RUNWAYS CLOSER THAN 2,500 FEET

- c. When landing behind a larger aircraft - crossing runway (figure 11) - cross above the larger aircraft's flight path.



**FIGURE 11. AVOIDANCE PROCEDURE FOR LANDING BEHIND
LARGER AIRCRAFT THAT IS USING A CROSSING RUNWAY**

- d. When landing behind a departing larger aircraft - same runway (figure 12) - note larger aircraft's rotation point, and land well before the rotation point.

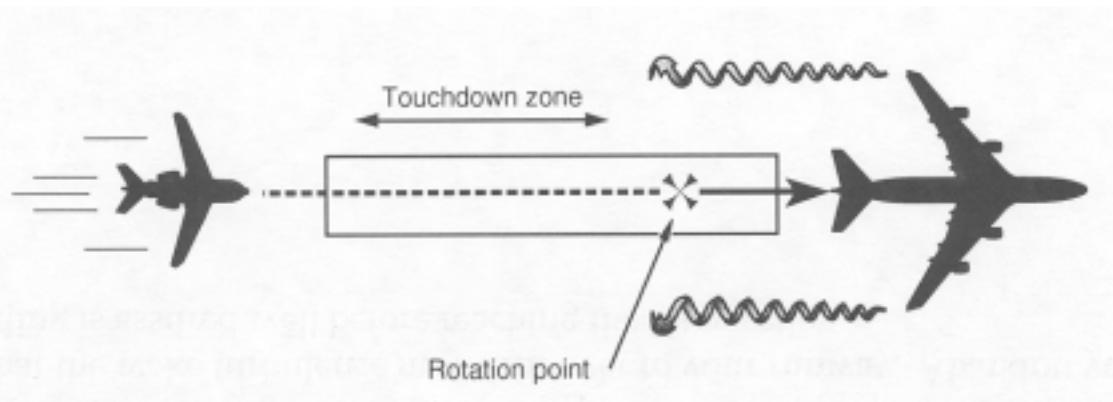


FIGURE 12. AVOIDANCE WHEN LANDING BEHIND A DEPARTING AIRCRAFT ON THE SAME RUNWAY

- e. When landing behind a departing larger aircraft - crossing runway - note larger aircraft's rotation point. If rotation is past the intersection, continue the approach and land before the intersection (figure 13). If larger aircraft rotates prior to the intersection, avoid flight below the larger aircraft's flight path. Abandon the approach unless a landing is ensured well before reaching the intersection (figure 14).

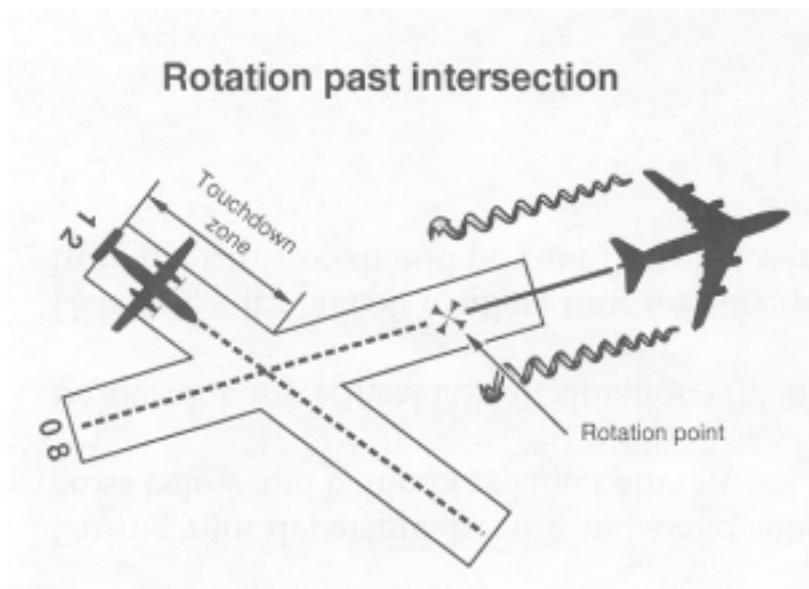


FIGURE 13. AVOIDANCE FOR LANDING BEHIND DEPARTING LARGER AIRCRAFT ON A CROSSING RUNWAY ROTATION POINT PAST THE INTERSECTION

Rotation prior to intersection

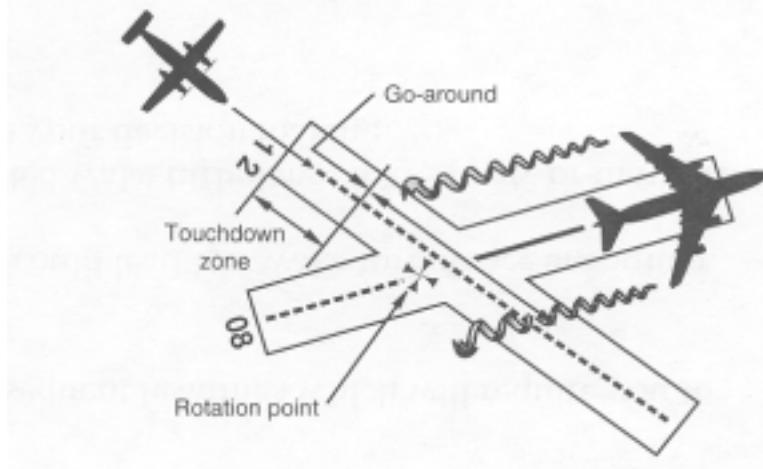


FIGURE 14. AVOIDANCE FOR LANDING WHEN LARGER DEPARTING AIRCRAFT ROTATES PRIOR TO THE INTERSECTION

- f. When departing behind a larger aircraft - same runway - note larger aircraft's rotation point, and rotate prior to larger aircraft's rotation point. Continue climb above the larger aircraft's climb path until turning clear of this wake (figure 15). Avoid subsequent headings which will cross below and behind aircraft (see figure 16). Be alert for any critical takeoff situation which could lead to a vortex encounter.

Avoidance Procedures: Takeoff



FIGURE 15. DEPARTING SAME RUNWAY BEHIND A LARGER AIRCRAFT

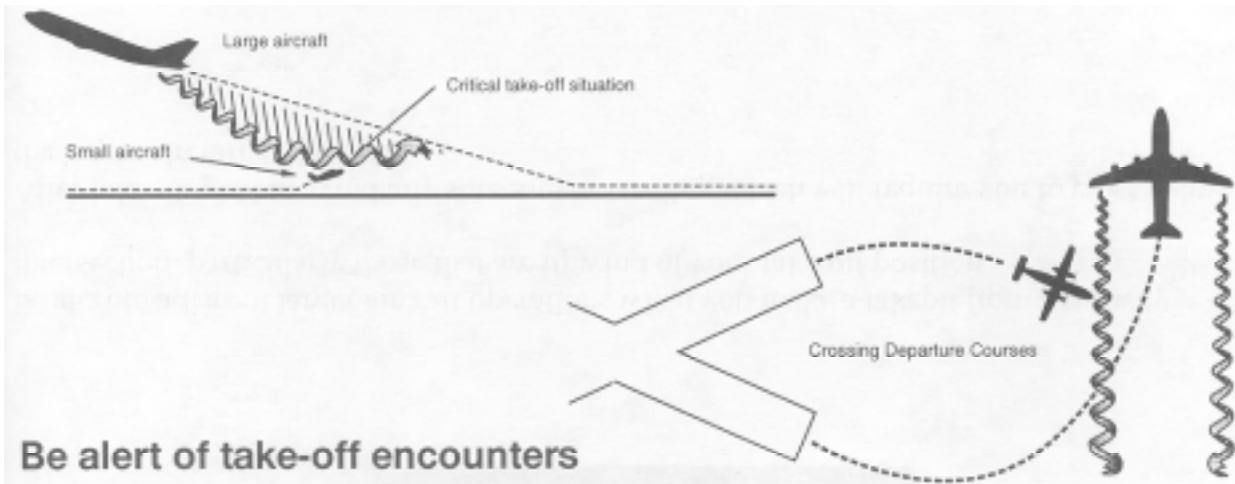


FIGURE 16. CRITICAL TAKEOFF SITUATION AND CROSSING DEPARTURE COURSES

g. Intersection takeoffs - same runway - be alert to adjacent large aircraft operations, particularly upwind of your runway. If intersection takeoff clearance is received, avoid subsequent heading which will cross below a larger aircraft's path.

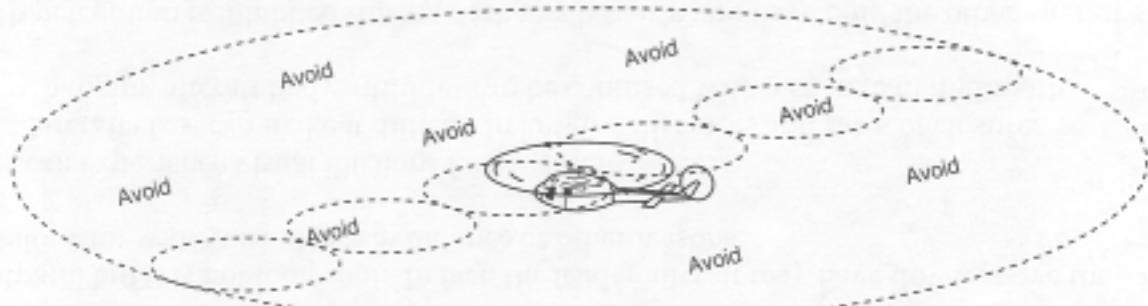
h. Departing or landing after a larger aircraft executing a low missed approach or touch-and-go landing. Because vortices settle and move laterally near the ground, the vortex hazard may exist along the runway and in your flight path after a larger aircraft has executed a low missed approach or a touch-and-go landing, particularly in light quartering wind conditions. You should ensure that an interval of at least 2 minutes has elapsed before your takeoff or landing.

i. En route VFR (1,000-foot altitude plus 500 feet). Avoid flight below and behind a larger aircraft's path. If a larger aircraft is observed above on the same track (meeting or overtaking), adjust your position laterally, preferably upwind.

10. HELICOPTERS. A hovering helicopter generates a downwash from its main rotor(s) similar to the “prop wash” of a conventional aircraft. However, in forward flight this energy is transformed into a pair of strong, high-speed trailing vortices similar to wing-tip vortices of larger fixed-wing aircraft. Pilots should avoid helicopter vortices since helicopter forward flight airspeeds are often very low which generate exceptionally strong wake turbulence (see figure 17).

Slow hover taxi or stationary hover

Avoid operations within distances of 3 times rotor diameter

**Forward flight, landing and departing helicopters**

Small aircraft, use caution behind/crossing behind

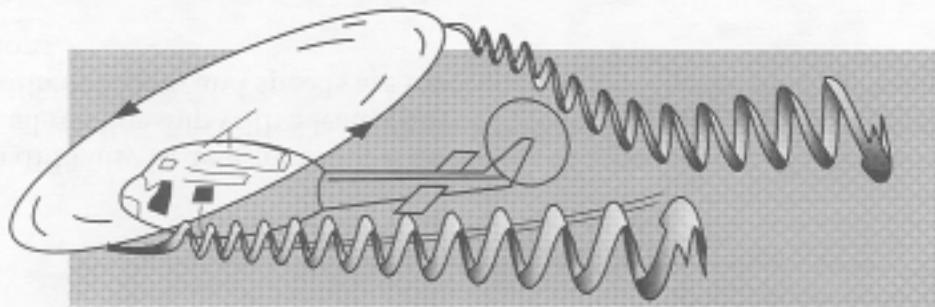


FIGURE 17. HELICOPTER VORTICES

11. JET ENGINE EXHAUST.

- a. During ground operations, jet engine blast (thrust stream turbulence) can cause damage and upsets if encountered at close range. Exhaust velocity versus distance studies at various thrust levels have shown a need for light aircraft to maintain an adequate separation during ground operations.

b. Engine exhaust velocities, generated by larger jet aircraft during ground operations and initial takeoff roll, dictate the desirability of lighter aircraft awaiting takeoff to hold well back of the runway edge at the taxiway hold line. Also, it is desirable to align the aircraft to face any possible jet engine blast effects. Additionally, in the course of running up engines and taxiing on the ground, pilots of larger aircraft should consider the effects of their jet blasts on other aircraft, vehicles, and maintenance and servicing equipment.

12. PILOT RESPONSIBILITY.

a. Government and industry groups are making concerted efforts to minimize or eliminate the hazards of trailing vortices. However, the flight disciplines necessary to ensure vortex avoidance during VFR operations must be exercised by the pilot. Vortex visualization and avoidance procedures should be exercised by the pilot using the same degree of concern as in collision avoidance.

b. Pilots are reminded that in operations conducted behind all aircraft, acceptance of instructions from air traffic control (ATC) in the following situations is an acknowledgment that the pilot will ensure safe takeoff and landing intervals, and accepts the responsibility for providing wake turbulence separation.

- (1) Traffic information,
- (2) Instructions to follow an aircraft, and
- (3) The acceptance of a visual approach clearance.

c. For operations conducted behind **heavy** aircraft, ATC will specify the word "**heavy**" when this information is known. Pilots of **heavy** aircraft should always use the word "**heavy**" in radio communications.

d. Heavy and large jet aircraft operators should use the following procedures during an approach to landing. These procedures establish a dependable baseline from which pilots of in-trail, lighter aircraft may reasonably expect to make effective flight path adjustments to avoid serious wake vortex turbulence.

- (1) Pilots of aircraft that produce strong wake vortices should make every attempt to fly on the established glidepath, not above it; or, if glidepath guidance is not available, to fly as closely as possible to a "3 to 1" glidepath, not above it.

EXAMPLE:

Fly 3,000 feet at 10 miles from touchdown, 1,500 feet at 5 miles, 1,200 feet at 4 miles, and so on to touchdown.

(2) Pilots of aircraft that produce strong wake vortices should fly as closely as possible to approach course centerline or to the extended centerline of the runway of intended landing as appropriate to conditions.

e. Pilots operating lighter aircraft on visual approaches in-trail to aircraft producing strong wake vortices should use the following procedures to assist in avoiding wake turbulence. These procedures apply only to those aircraft that are on visual approaches.

(1) Pilots of lighter aircraft should fly on or above the glidepath. Glidepath reference may be furnished by an ILS, by a visual approach slope system, by other ground-based approach slope guidance systems, or by other means. In the absence of visible glidepath guidance, pilots may very nearly duplicate a 3-degree glideslope by adhering to the "3 to 1" glidepath principles.

EXAMPLE:

Fly 3,000 feet at 10 miles from touchdown, 1,500 feet at 5 miles, 1,200 feet at 4 miles, and so on to touchdown.

(2) If the pilot of the lighter following aircraft has visual contact with the preceding heavier aircraft and also with the runway, the pilot may further adjust for possible wake vortex turbulence by the following practices:

- (a) Pick a point of landing no less than 1,000 feet from the arrival end of the runway.
- (b) Establish a line-of-sight to that landing point that is above and in front of the heavier preceding aircraft.
- (c) When possible, note the point of landing of the heavier preceding aircraft and adjust point of intended landing as necessary.

EXAMPLE:

A puff of smoke may appear at the 1,000-foot markings of the runway, showing that touchdown was that point; therefore, adjust point of intended landing to the 1,500-foot markings.

- (d) Maintain the line-of-sight to the point of intended landing above and ahead of the heavier preceding aircraft; maintain it to touchdown.
 - (e) Land beyond the point of landing of the preceding heavier aircraft.
- (3) During visual approaches pilots may ask ATC for updates on separation and groundspeed with respect to heavier preceding aircraft, especially when there is any question of safe separation from wake turbulence.

(4) Aircraft Classes. For the purposes of Wake Turbulence Separation Minima, ATC classifies aircraft as Heavy, Large, and Small as follows:

- (a) Heavy-Aircraft capable of takeoff weights of more than 255,000 pounds whether or not they are operating at this weight during a particular phase of flight.
- (b) Large-Aircraft of more than 41,000 pounds, maximum certificated takeoff weight, up to 255,000 pounds.
- (c) Small-Aircraft of 41,000 pounds or less maximum certificated takeoff weight.

13. PILOT AWARENESS INTERVENTION. There is a small segment of the aviation community that have become convinced that wake vortices may “bounce” up to twice their nominal steady state height (with a 200-foot span aircraft the “bounce” height could reach approximately 200 feet above ground level (AGL)). This conviction is based on a single unsubstantiated report of an apparent coherent vortical flow that was seen in the volume scan of a research sensor. No one can say what conditions cause vortex bouncing, how high they bounce, at what angle they bounce, nor how many times a vortex may bounce. On the other hand, no one can say for certain that vortices never “bounce.” Test data have shown that vortices can rise with the air mass in which they are embedded. Wind shear, particularly, can cause vortex flow field “tilting.” Also, ambient thermal lifting and orographic effects (rising terrain or tree lines) can cause a vortex flow field to rise. In view of the foregoing, pilots are reminded that they should be alert at all times for possible wake vortex encounters when conducting approach and landing operations. The pilot has the ultimate responsibility for ensuring appropriate separations and positioning of the aircraft in the terminal area to avoid the wake turbulence created by a preceding aircraft.

James J. Ballough
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