C

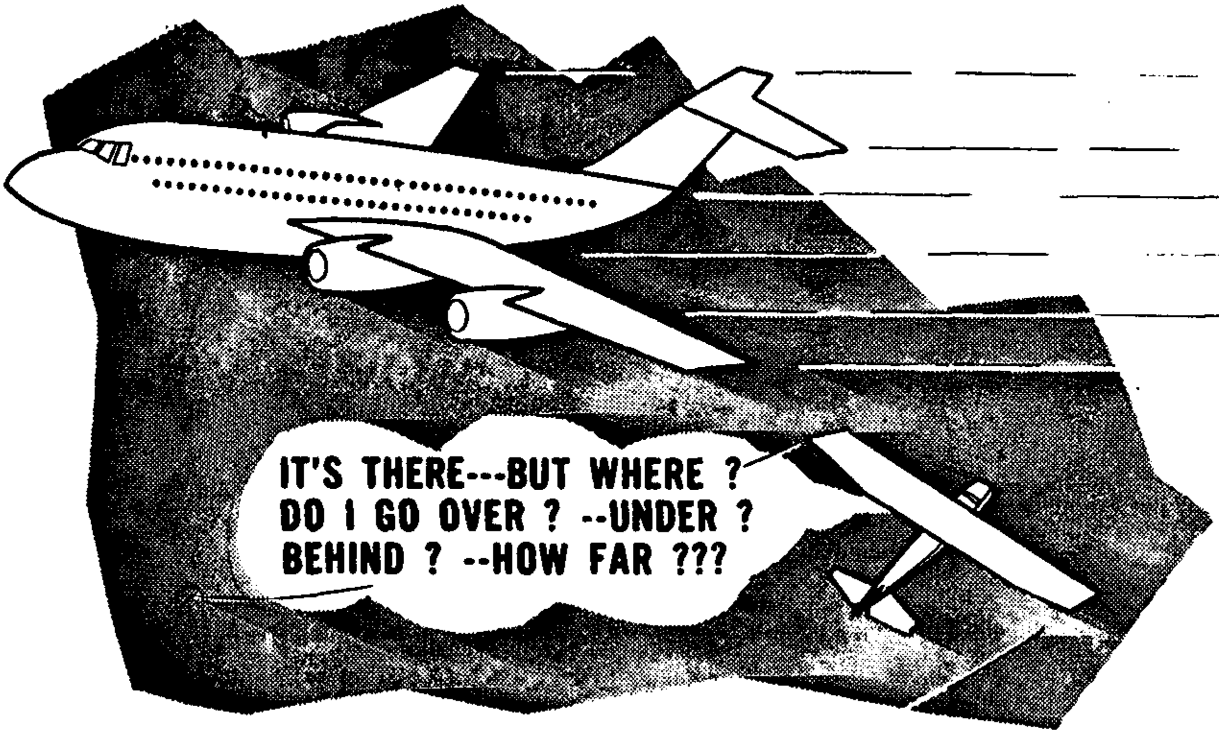
AC NO: 90-23D

DATE: 15 Dec 72

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: AIRCRAFT WAKE TURBULENCE



1. PURPOSE. This advisory circular alerts pilots to the hazards of aircraft trailing vortex wake turbulence and recommends related operational procedures.

2. CANCELLATION. AC 90-23C, Wake Turbulence, dated 16 May 1972.

Initiated by: AFS-424

3. INTRODUCTION. Every airplane generates a wake while in flight. Initially, when pilots encountered this wake in flight, 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 roll control capability of some aircraft. Further, turbulence generated within the vortices can damage aircraft components and equipment if encountered at close range. The pilot must learn to envision the location of the vortex wake generated by large aircraft and adjust his 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 roll up of the airflow aft of the wing resulting in swirling air masses trailing downstream of the wing tips. After the roll up is completed, the wake consists of two counter rotating cylindrical vortices.

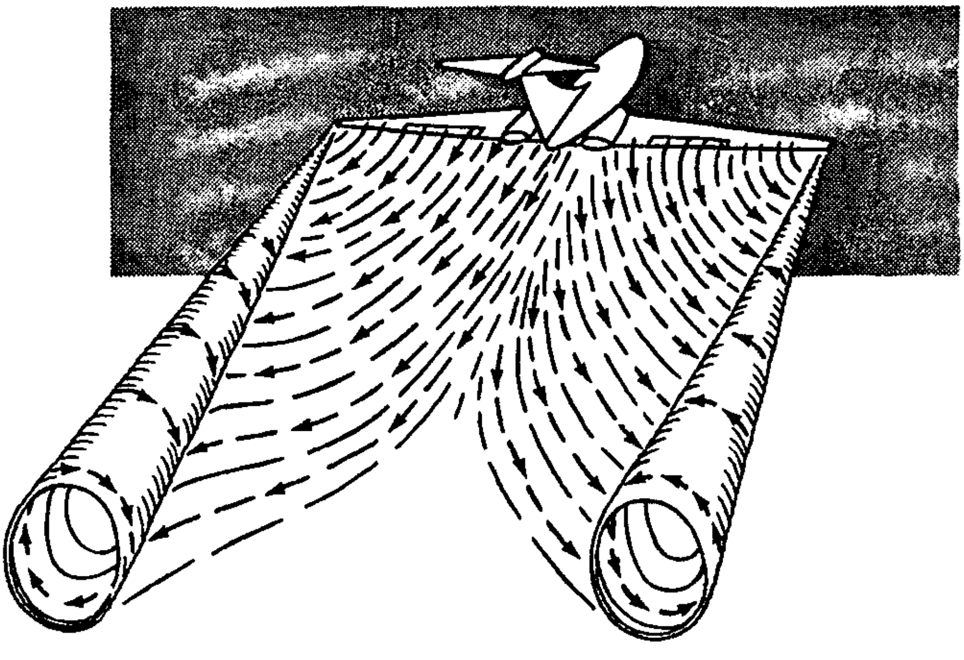


FIGURE 1. The rolling up process

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 as well as by change in speed. However, as the basic factor is weight, the vortex strength increases proportionately. During a recent test, peak vortex tangential velocities were recorded at 224 feet per second, or about 133 knots. The greatest vortex strength occurs when the generating aircraft is HEAVY - CLEAN - SLOW. Figure 2 shows smoke visualization of a vortex photographed during recent tests.

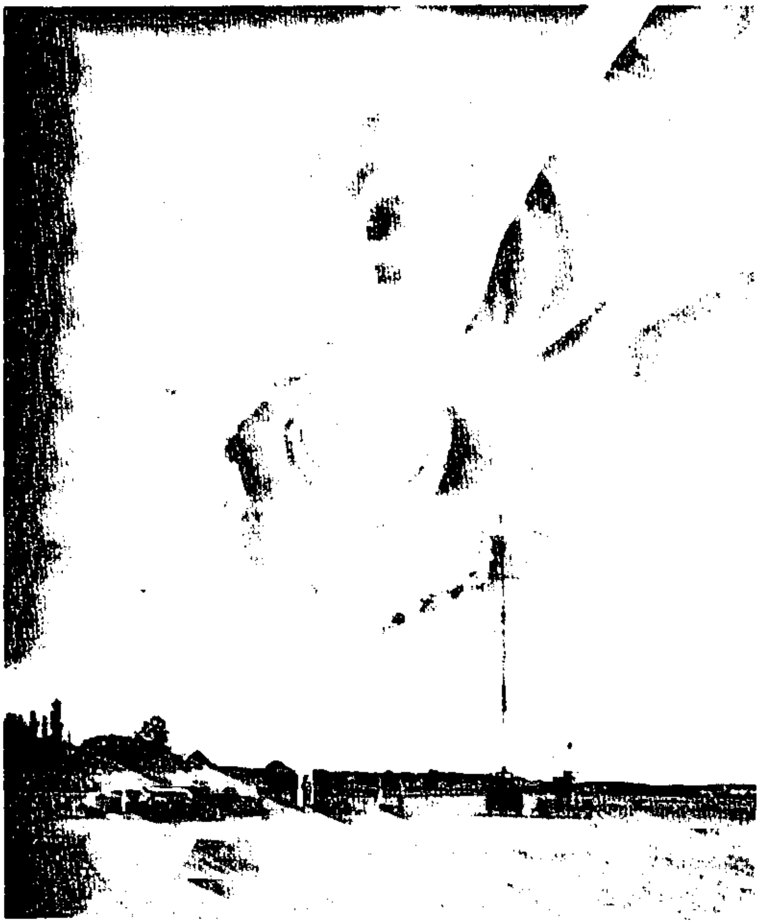


FIGURE 2. Typical vortex flow field outlined by smoke

6. INDUCED ROLL. 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 rolling capability of the encountering aircraft. In flight experiments, aircraft have been intentionally flown directly up trailing vortex cores of large aircraft. It was shown that the capability of an aircraft to counteract the roll imposed by the wake vortex primarily depends on the wing span and counter control responsiveness of the encountering aircraft.

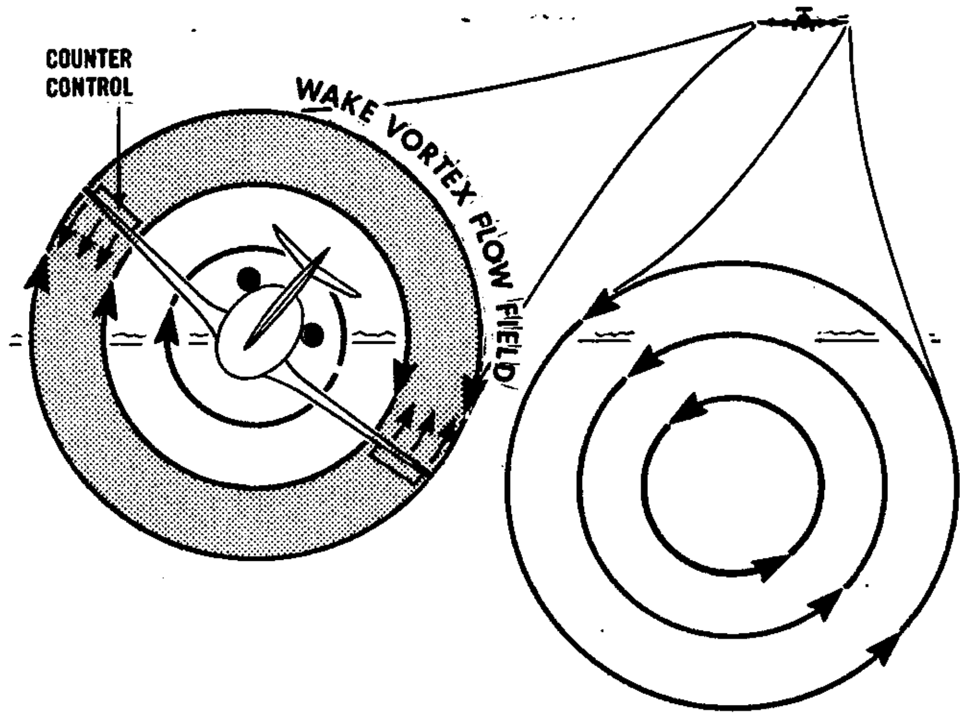


FIGURE 3. Induced Roll

Counter control is usually effective and induced roll minimal in cases where the wing span and ailerons of the encountering aircraft extend beyond the rotational flow field of the vortex. It is more difficult for aircraft with short wing span (relative to the 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 large aircraft requires the respect of all pilots.

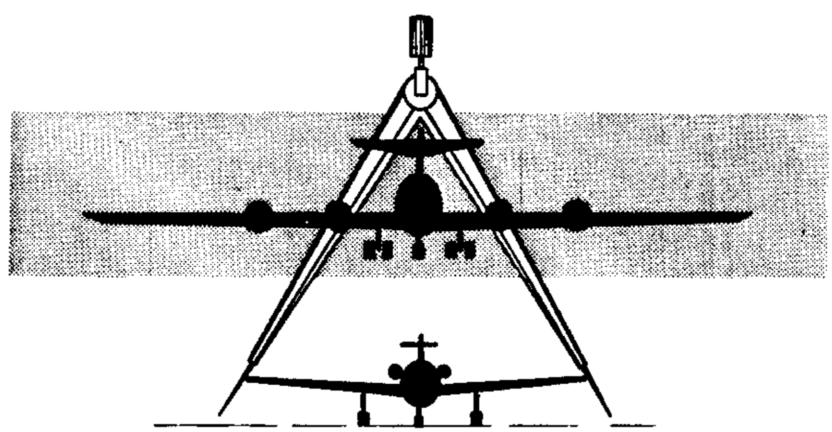


FIGURE 4. Relative Span

7. VORTEX BEHAVIOR. Trailing vortices have certain behavioral characteristics which can help a pilot 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 touchdown pilots should note the rotation or touchdown point of the preceeding aircraft.

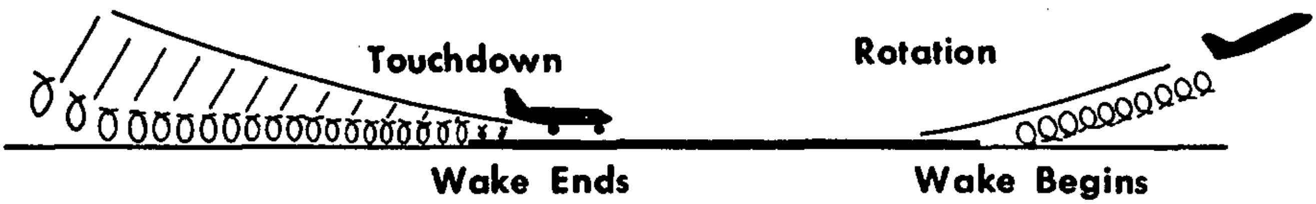
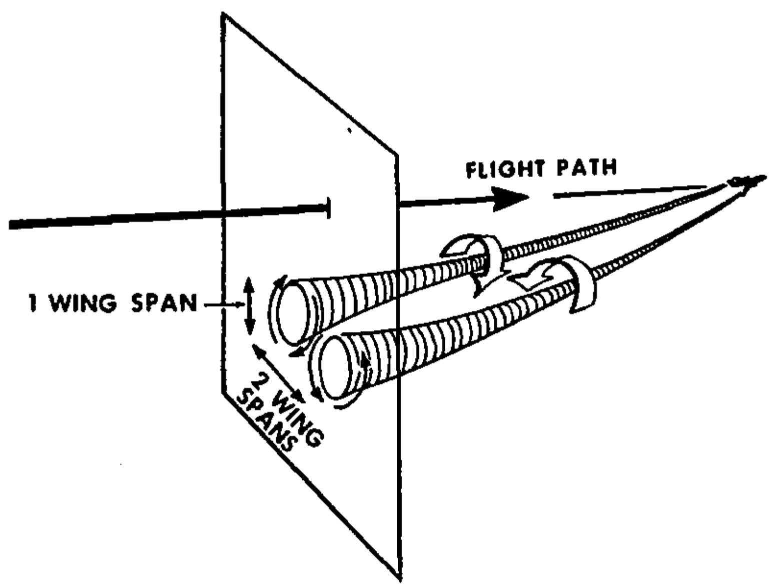


FIGURE 5.

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 vortex flow field, in a plane cutting thru the wake (Figure 6) at any point downstream, covers an area about 2 wing spans in width and one wing span in depth. The vortices remain so spaced (about a wing span apart) even drifting with the wind, at altitudes greater than a wing span 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.



Vortex Flow Field in Aircraft Wake

FIGURE 6.

c. Flight tests have shown that the vortices from large aircraft sink at a rate of about 400 to 500 feet per minute. They tend to level off at a distance about 900 feet below the flight path of the generating aircraft. Vortex strength diminishes with time and distance behind the generating aircraft. Atmospheric turbulence hastens breakup.

Pilots should fly at or above the large aircraft's flight path, altering course as necessary to avoid the area behind and below the generating aircraft.

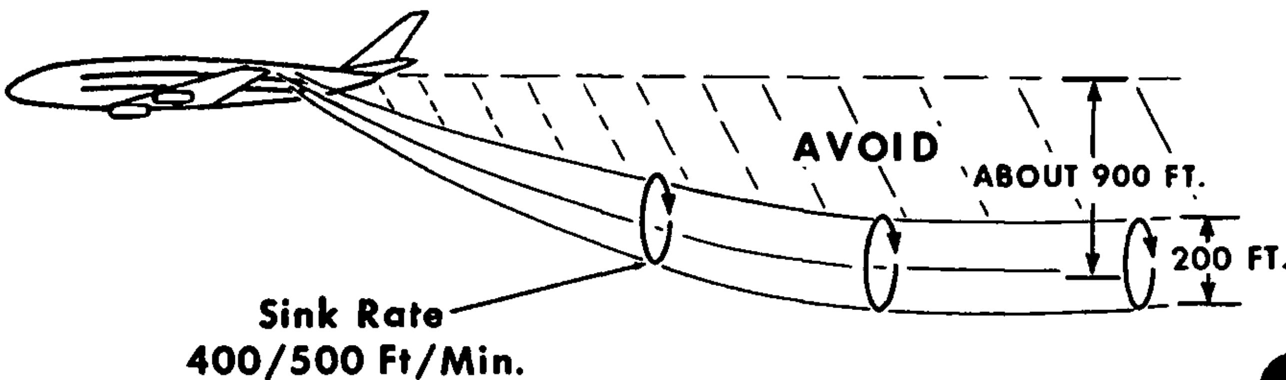


FIGURE 7.

d. When the vortices of large aircraft sink close to the ground (within about 200 feet), they tend to move laterally over the ground at a speed of about 5 knots. (Figure 8).

A crosswind will decrease the lateral movement of the upwind vortex and increase the movement of the downwind vortex (Figure 9). Thus a light wind of 3 to 7 knots could result in the upwind vortex remaining in the touchdown zone for a period of time (Figure 10) 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 (Figure 10)

Pilots should be alert to large aircraft upwind from their approach and takeoff flight paths.

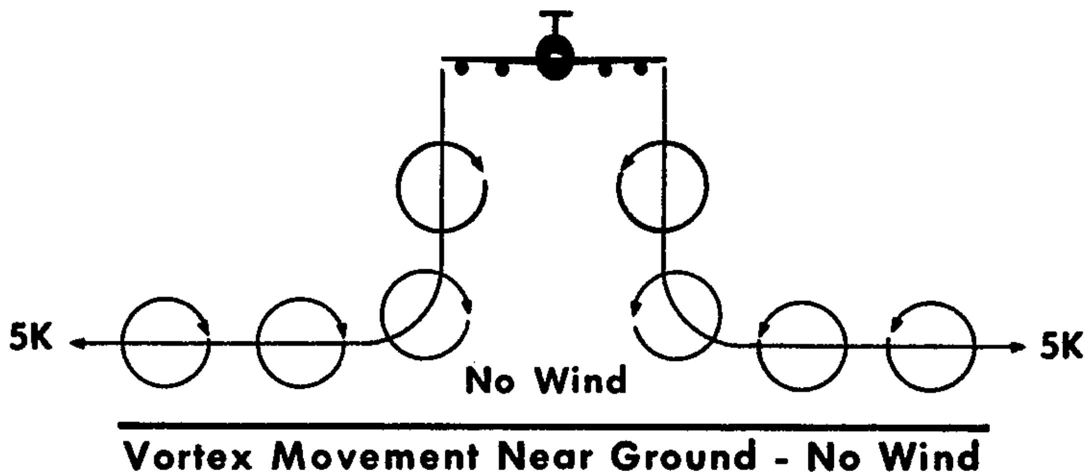


FIGURE 8.

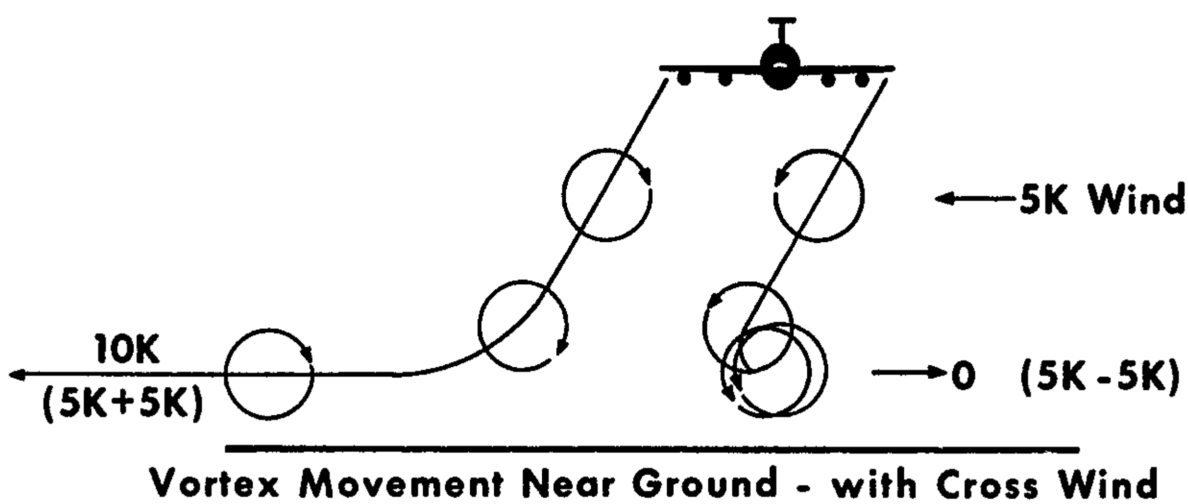


FIGURE 9.

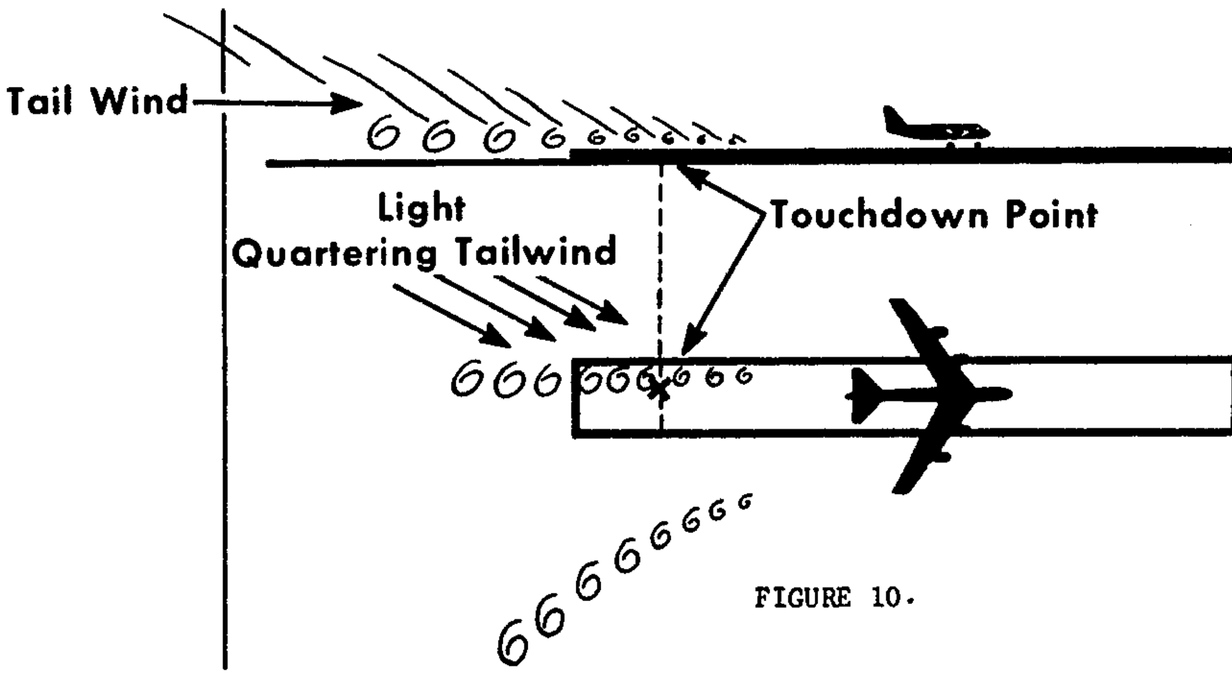


FIGURE 10.

8. <u>OPERATIONS PROBLEM AREAS</u>. A wake encounter is not necessarily hazardous. It can be one or more jolts with varying severity depending upon the direction of the encounter, 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 with the vortex trail or 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 situations where the vortices could:

a. Remain in the touchdown area.

b. Drift from aircraft operating on a nearby runway.

c. Sink into takeoff or landing path from a crossing runway.

d. Sink into the traffic patterns from other airport operations.

e. Sink into the flight path of VFR flights operating at the hemispheric altitude 500 feet below.

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

9. VORTEX AVOIDANCE PROCEDURES. Under certain conditions, airport traffic controllers apply procedures for separating aircraft from heavy jet aircraft. The controllers will also provide VFR aircraft, with whom they are in communication and which in the tower's opinion may be adversely affected by wake turbulence from a large aircraft, the position, altitude and direction of flight of the large aircraft followed by the phrase "CAUTION - WAKE TURBULENCE." WHETHER OR NOT A WARNING HAS BEEN GIVEN, HOWEVER, THE PILOT IS EXPECTED TO ADJUST HIS OPERATIONS AND FLIGHT PATH AS NECESSARY TO PRECLUDE SERIOUS WAKE ENCOUNTERS.

The following vortex avoidance procedures are recommended for the situation shown.

a. Landing behind a large aircraft - same runway:

Stay at or above the large aircraft's final approach flight path--note his touchdown point--land beyond it.

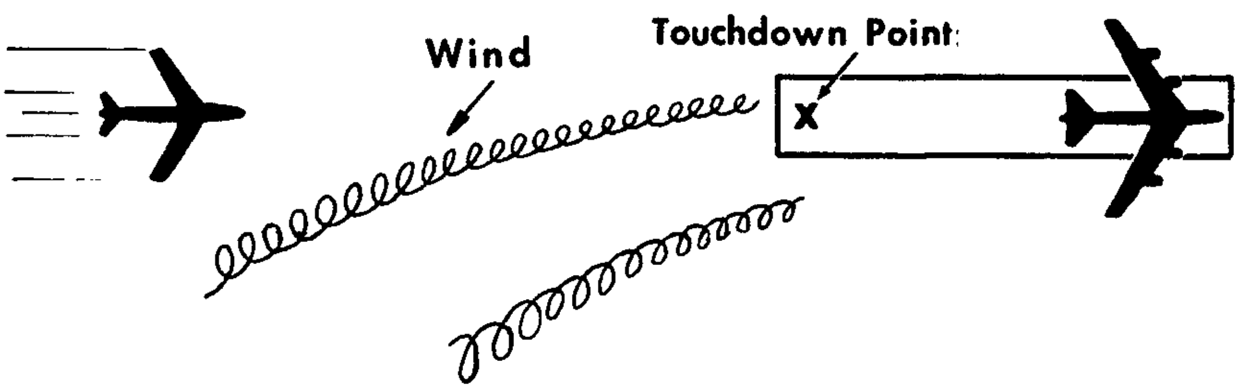


FIGURE 11.

b. Landing behind a large aircraft - when parallel runway is closer than 2,500 feet: (FIGURE 12)

Consider possible drift to your runway. Stay at or above the large aircraft's final approach flight path--note his touchdown point.

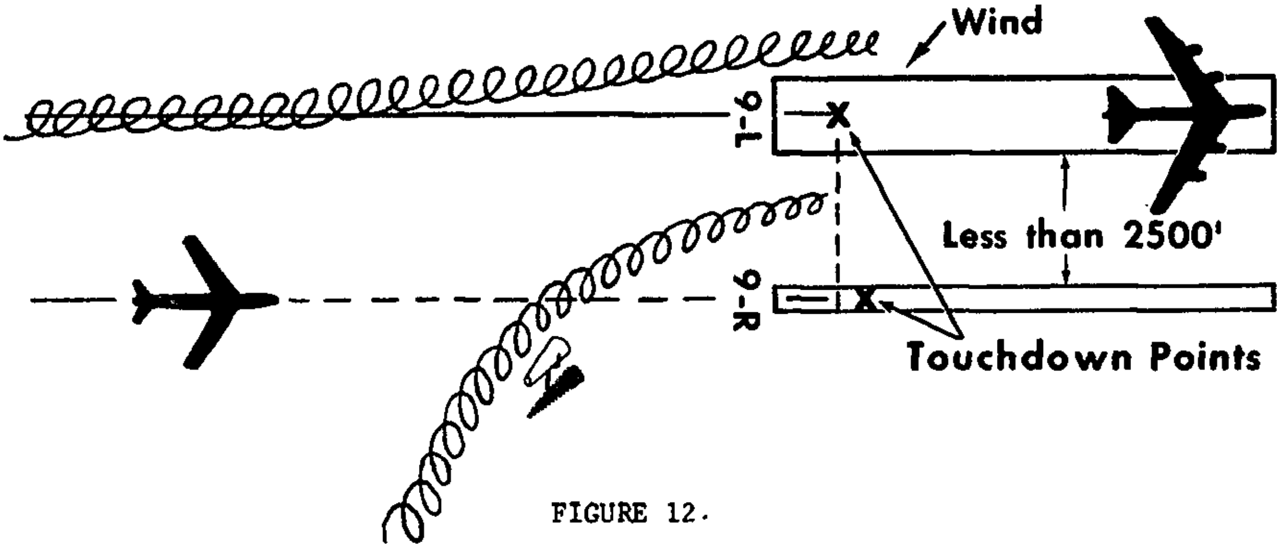


FIGURE 12.

c. Landing behind a large aircraft - crossing runway

Cross above the large aircraft's flight path.

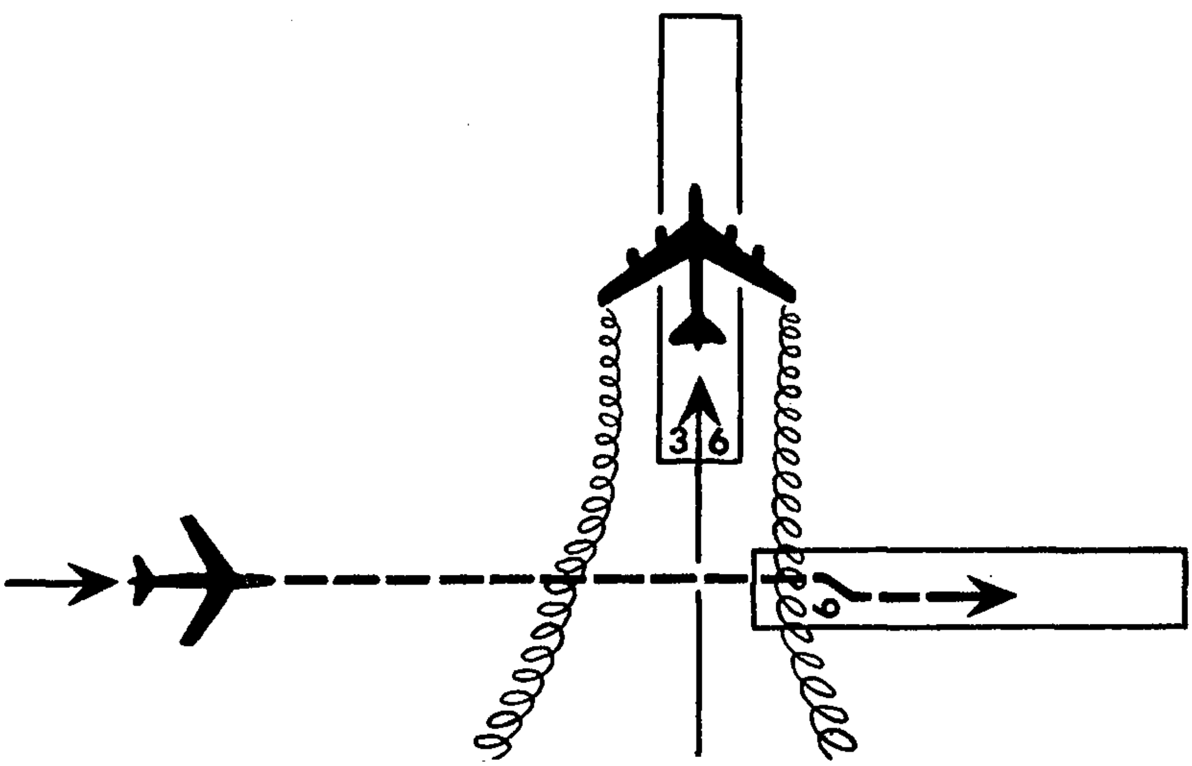


FIGURE 13.

d. Landing behind a departing large aircraft - same runway:

Note large aircraft's rotation point--land well prior to rotation point.

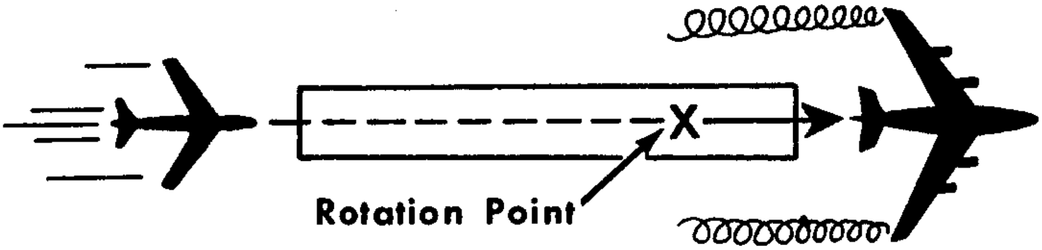


FIGURE 14.

e. Landing behind a departing large aircraft - crossing runway:

Note large aircraft's rotation point--if past the intersection--continue the approach--land prior to the intersection (Figure 15). If large aircraft rotates prior to the intersection, avoid flight below the large aircraft's flight path. Abandon the approach unless a landing is assured well before reaching the intersection (Figure 16).

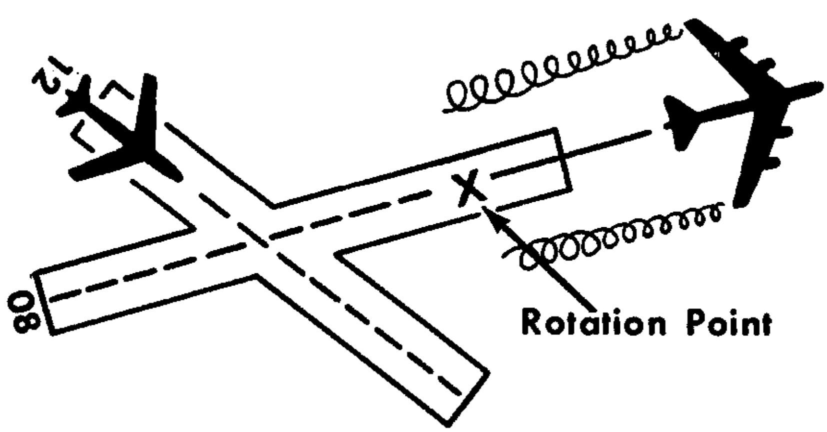


FIGURE 15.

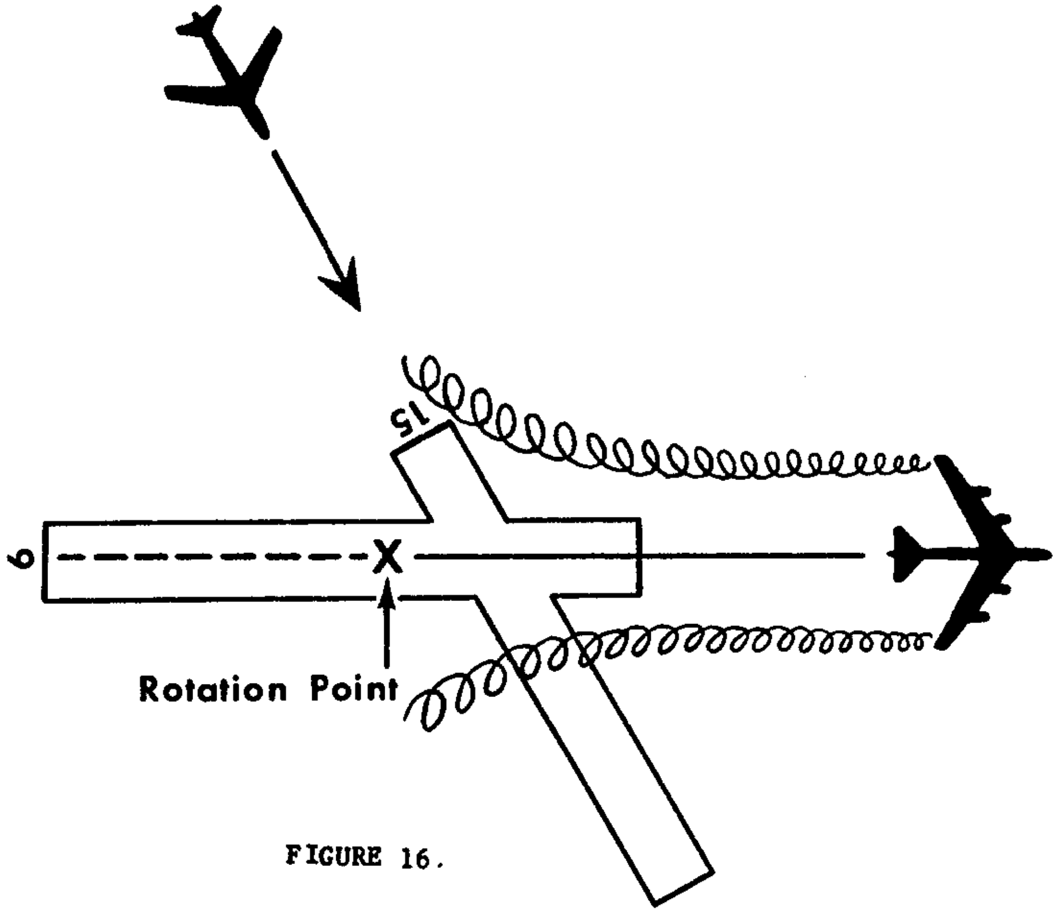


FIGURE 16.

f. Departing behind a large aircraft:

Note large aircraft's rotation point--rotate prior to large aircraft's rotation point--continue climb above and stay upwind of the large aircraft's climb path until turning clear of his wake (Figure 17). Avoid subsequent headings which will cross below and behind a large aircraft (Figure 18). Be alert for any critical takeoff situation which could lead to a vortex encounter (Figure 19).

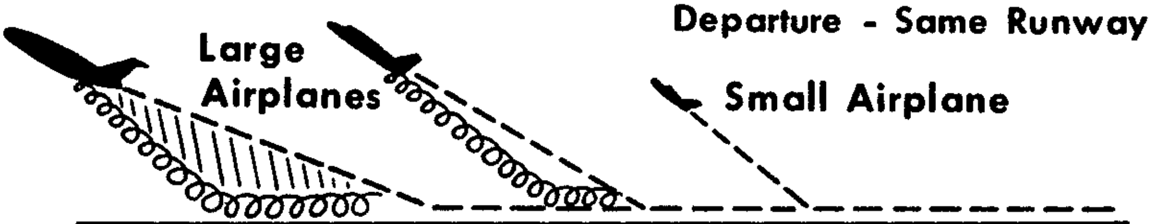


FIGURE 17.

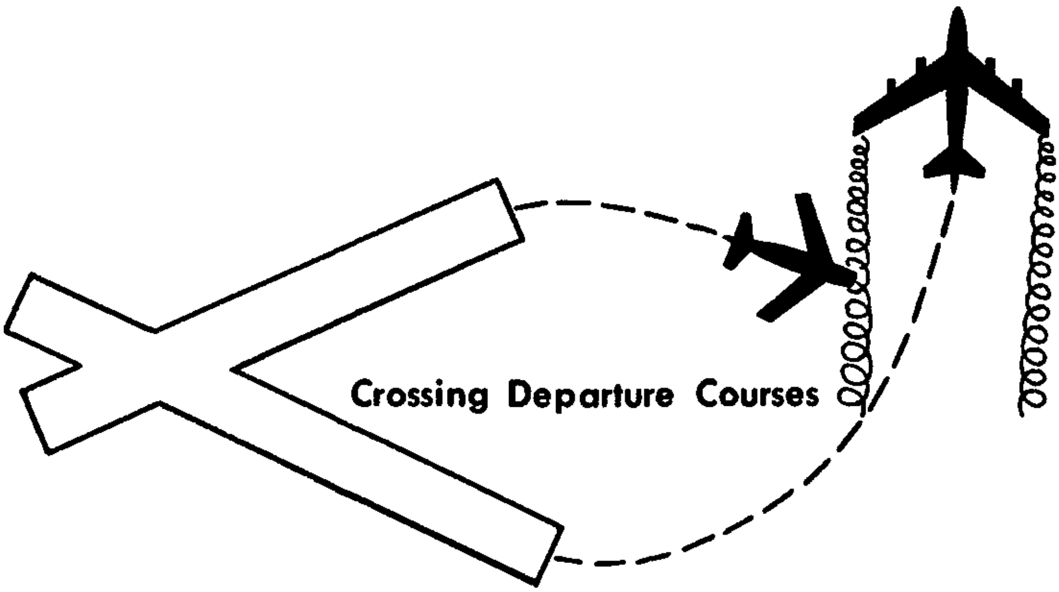


FIGURE 18.

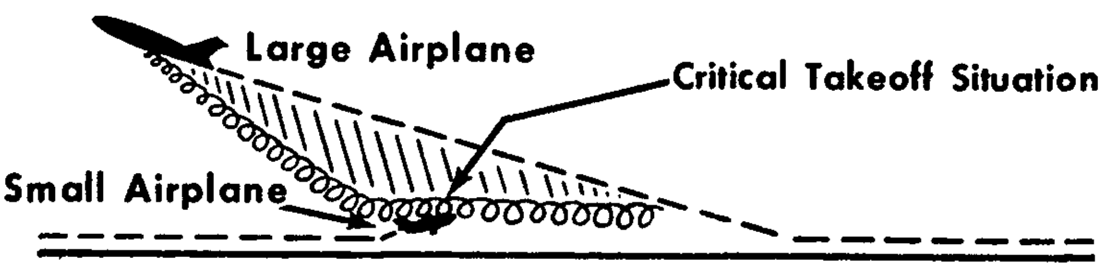


FIGURE 19.

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 large aircraft's path.

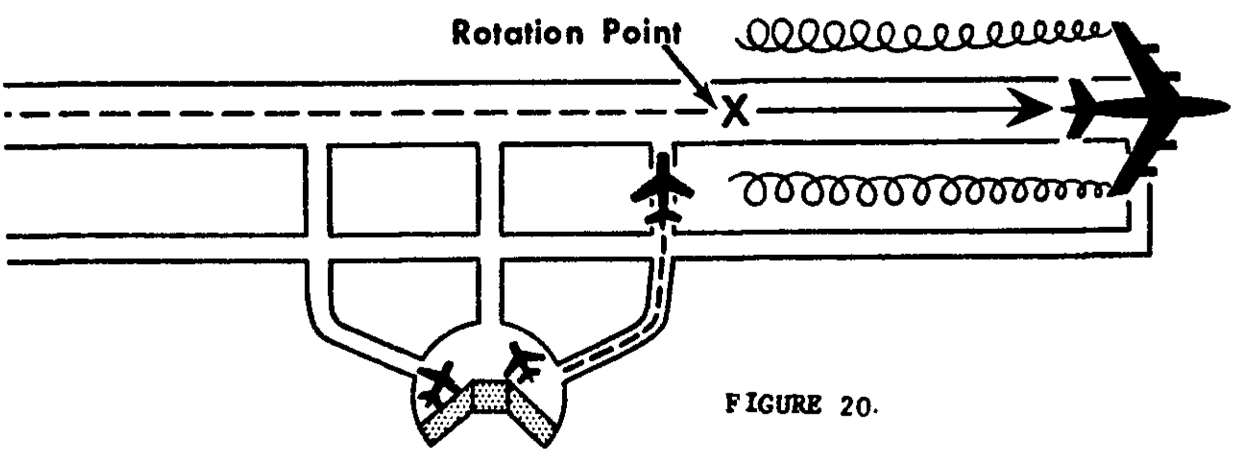


FIGURE 20.

h. Departing or landing after a large 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 large aircraft has executed a low missed approach or a touch-and-go landing, particularly in light quartering wind conditions. You should assure that an interval of at least 2 minutes has elapsed before your takeoff or landing.

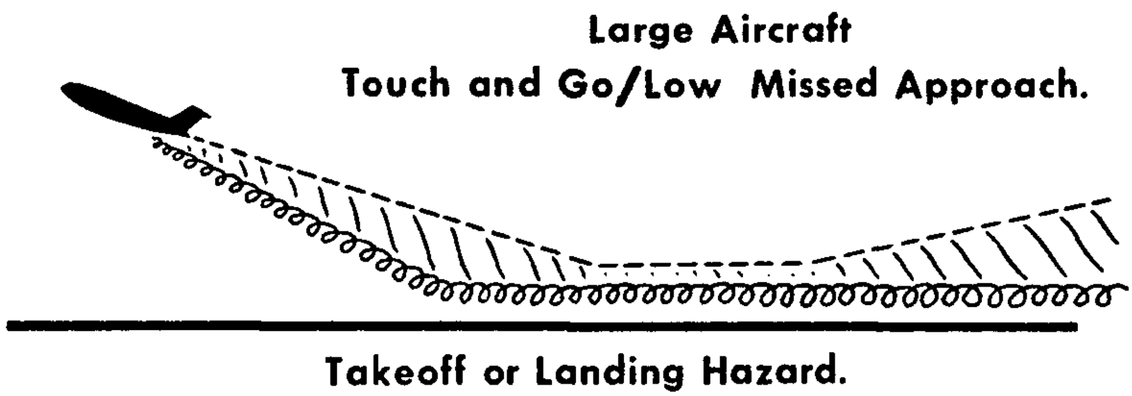


FIGURE 21.

i. Enroute VFR - (thousand-foot altitude plus 500 feet).

Avoid flight below and behind a large aircraft's path. If a large aircraft is observed above on the same track (meeting or overtaking) adjust your position laterally, preferably upwind.

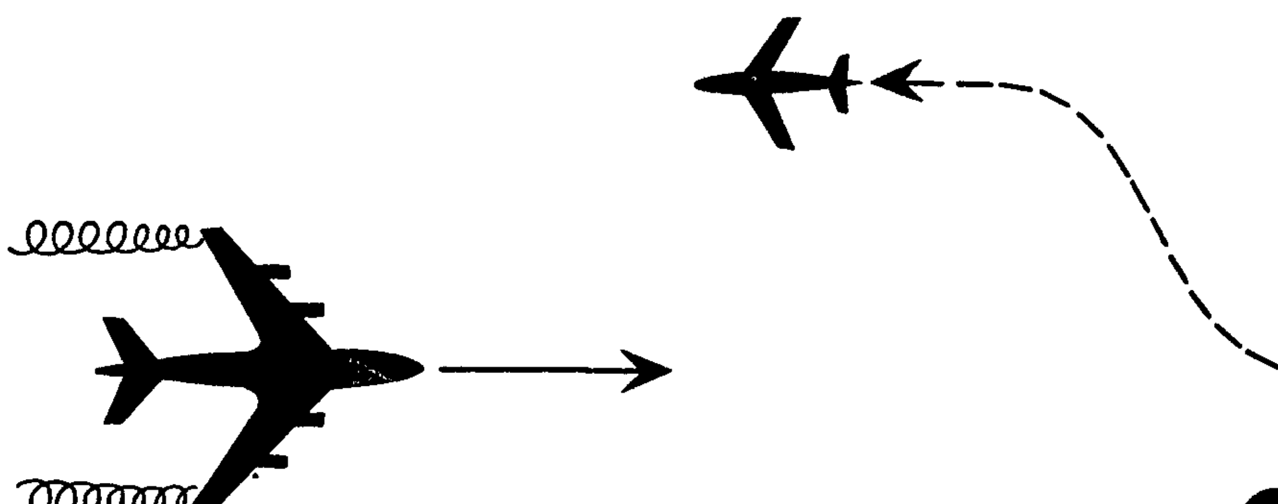


FIGURE 22.

10. HELICOPTERS. A hovering helicopter generates a downwash from its main rotor(s) similar to the prop blast of a conventional aircraft. However, in forward flight, this energy is transformed into a pair of trailing vortices similar to wing-tip vortices of fixed wing aircraft. Pilots of small aircraft should avoid the vortices as well as the downwash.

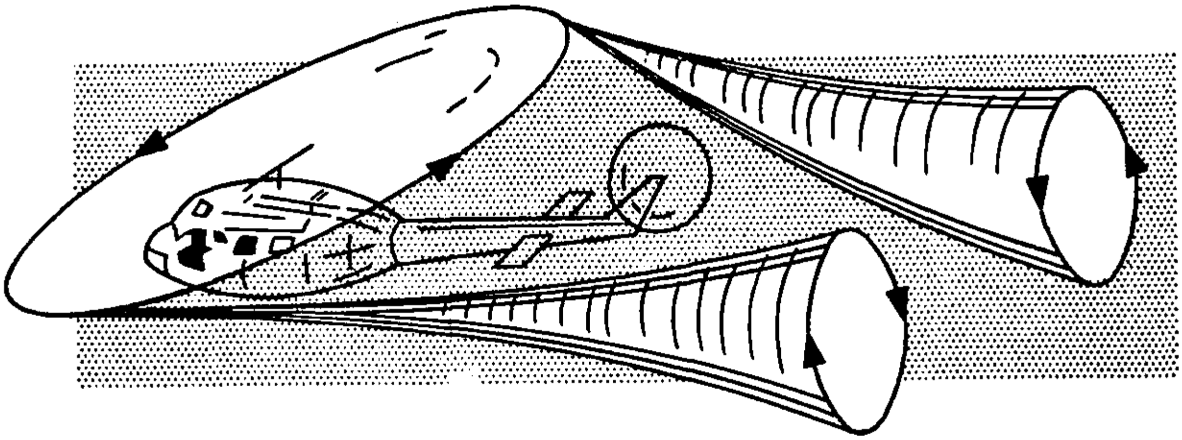
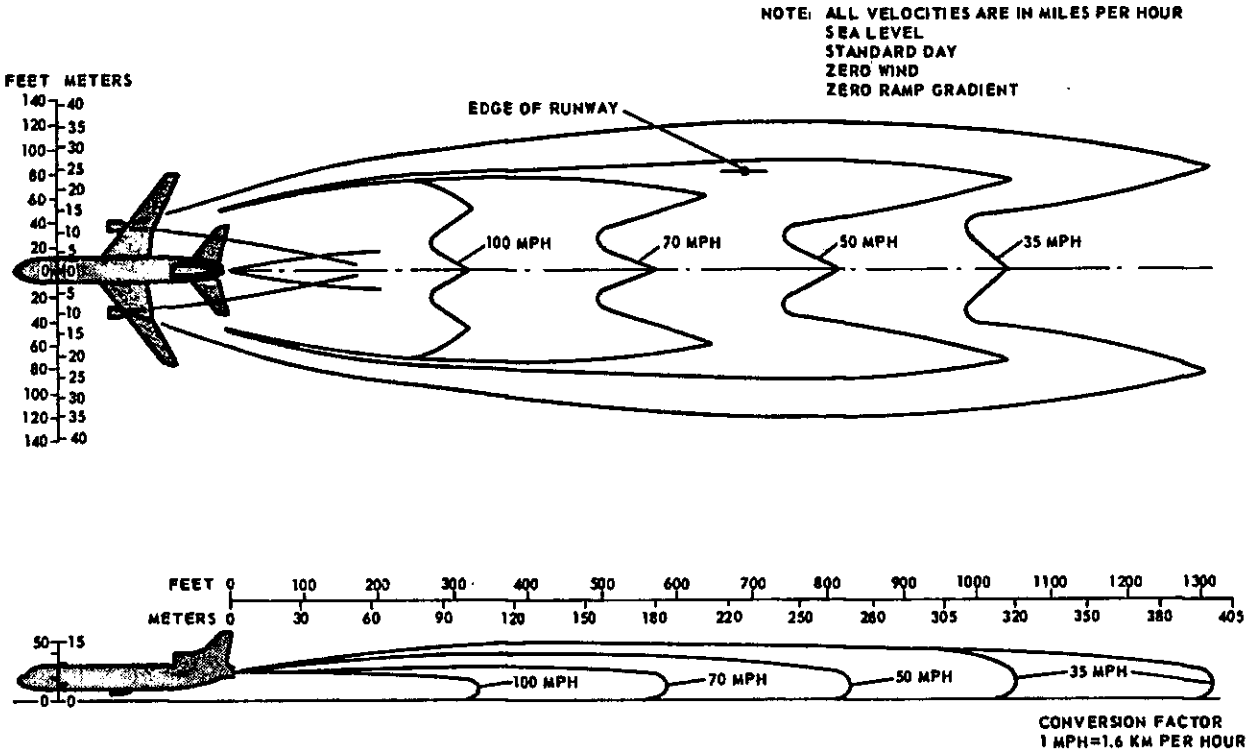


FIGURE 23. Helicopter Vortices.

11. JET ENGINE EXHAUST. 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. Below are examples of the distance requirements to avoid exhaust velocities of greater than 25 MPH:

25 MPH VELOCITY	B-727	DC-8	DC-10
Takeoff Thrust	550 Ft.	700 Ft.	2100 Ft.
Breakaway Thrust	200 Ft.	400 Ft.	850 Ft.
Idle Thrust	150 Ft.	35 Ft.	350 Ft.

Engine exhaust velocities generated by large jet aircraft during initial takeoff roll and the drifting of the turbulence in relation to the crosswind component dictate the desireability of lighter aircraft awaiting takeoff to hold well back of the runway edge of taxiway hold line; also, the desirability of aligning the aircraft to face the possible jet engine blast movement. Additionally, in the course of running up engines and taxiing on the ground, pilots of large aircraft in particular should consider the effects of their jet blasts on other aircraft. An illustration of exhaust velocities behind a typical "wide-body" or or jumbo jet is shown in Figure 24.



JET ENGINE EXHAUST VELOCITY CONTOURS, TAKEOFF POWER

FIGURE 24.

The FAA has established new standards for the location of taxiway hold lines at airports served by air carriers as follows:

Taxiway holding lines will be established at 100 feet from the edge of the runway, except at locations where "heavy jets" will be operating, the taxiway holding line markings will be established at 150 feet. (The "heavy jet" category applies to those aircraft capable of taking off at gross weights of 300,000 pounds or more. Some B-707 and DC-8 type aircraft are included.)

12. PILOT RESPONSIBILITY. Government and industry groups are making concerted efforts to minimize or eliminate the hazards of trailing vortices. However, the flight disciplines necessary to assure 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.

Pilots are reminded that in operations conducted behind all aircraft, acceptance from ATC of:

1. Traffic information, or

2. Instructions to follow an aircraft, or

3. The acceptance of a visual approach clearance,

is an acknowledgment that the pilot will ensure safe takeoff and landing intervals and accepts the responsibility of providing his own wake turbulence separation.

For VFR departures behind heavy jet aircraft, air traffic controllers are required to use at least a two minute separation interval unless a pilot has initiated a request to deviate from the two-minute interval and has indicated acceptance of responsibility for maneuvering his aircraft so as to avoid the wake turbulence hazard.

Operational Tips For Light Aircraft
How to Avoid Vortex Wake

1. Lift Off Short of Large Aircraft Rotation Point.
2. Land Well Beyond Large Aircraft Touchdown Point.
3. Pass Over Flight Path of Large Aircraft, or At Least 1000' Under.
4. Stay to Windward of Large Aircraft Flight Paths.
5. Keep Alert, Specially on Calm Days When Vortices Persist Longest.

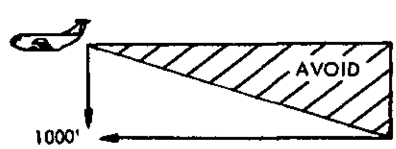


FIGURE 25.

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