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AC NO: 90-23B

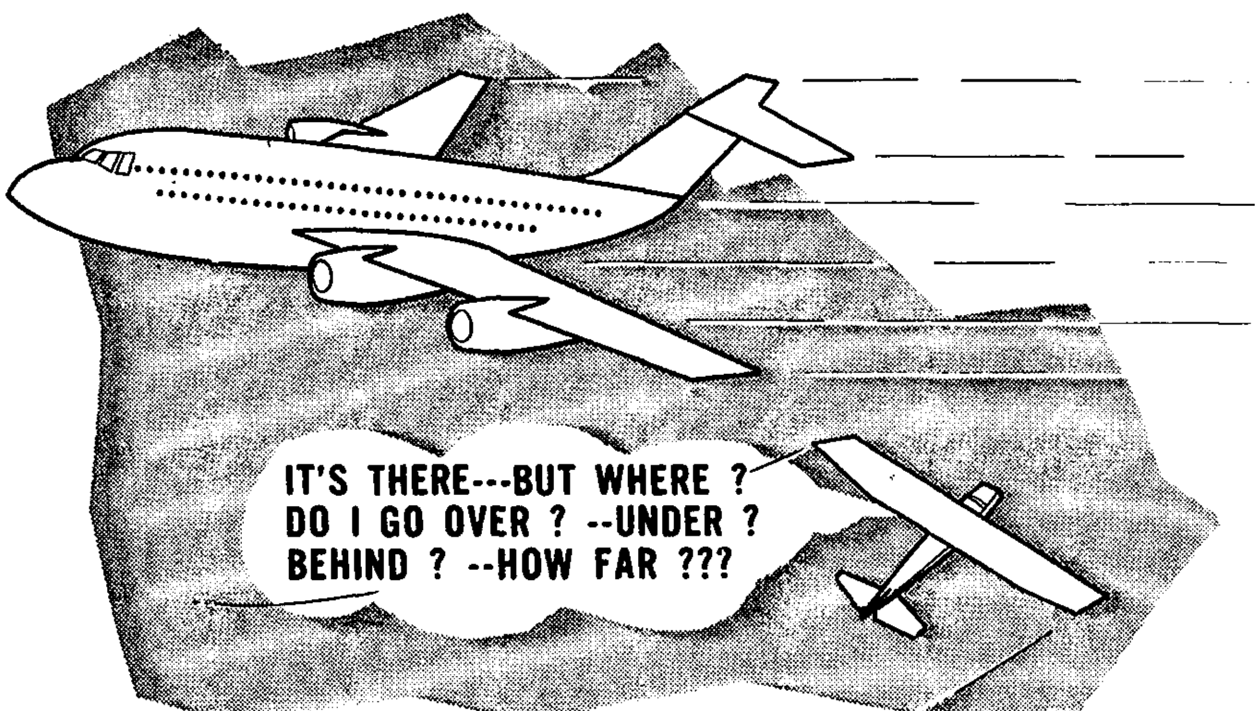
DATE: 17 May 71

Repl. by 23C

ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: WAKE TURBULENCE



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

2. CANCELLATION. AC 90-23A, Wake Turbulence. (Also replaces "Advance Copy" AC 90-23B, dated 19 February 1971, which received limited distribution.)

Initiated by: FS-60

3. INTRODUCTION. Every airplane generates a wake while in flight. Initially it was believed to be "prop wash." Later knowledge found this disturbance to be a pair of counter rotating vortices trailing from the wing tips. As aircraft became larger and heavier, the intensity of the vortices began to pose problems for smaller aircraft. Some of today's jet aircraft, and particularly the new (civil and military) jumbo jets, generate vortices with roll velocities 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 a large aircraft and adjust his flight path accordingly.

4. VORTEX GENERATION. Lift is generated by creating a pressure differential over the wing surfaces. The lowest pressure is found near the center of the upper surface. This tends to draw the airflow over the top of the wing inward from the tip toward the fuselage. Similarly, the highest relative pressure, found near the center of the lower surface, makes the airflow under the wing bend outward toward the tip in an effort to equalize the pressure. The resulting circulation and the downwash effect of the airflow over the wing causes the air leaving each trailing edge to form a vortex sheet which rolls itself up into a swirling spiral of air aft of the wing tips. After the roll up is completed, the wake consists of two counter rotating vortices. On modern swept-wing aircraft, the roll up process is well underway even before the flow leaves the wing tips.

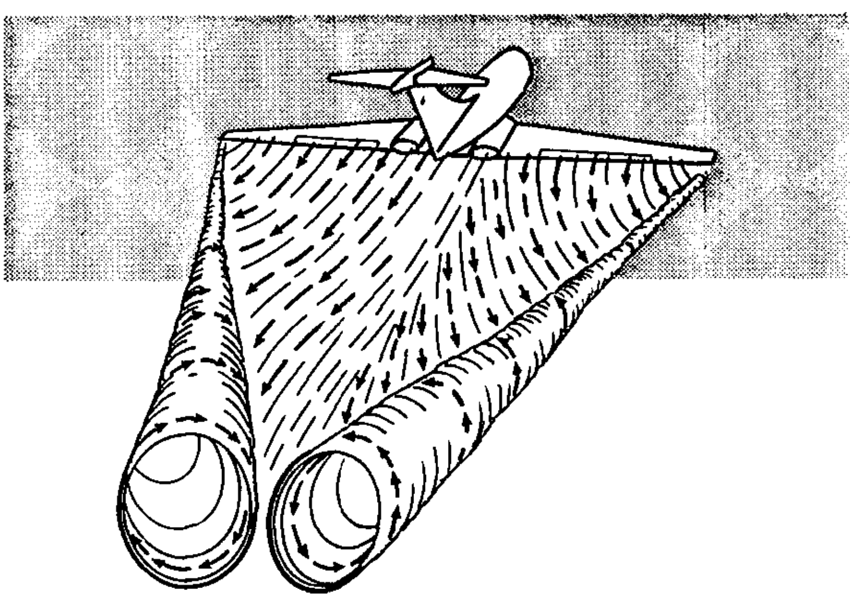


FIGURE 1. The rolling up process.

5. VORTEX STRENGTH. The strength of the vortex is governed primarily 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, the basic factor is weight, and the vortex strength increases with increases in weight and span loading. During a recent test, vortex tangential velocities were recorded at 150 feet per second, or about 90 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.

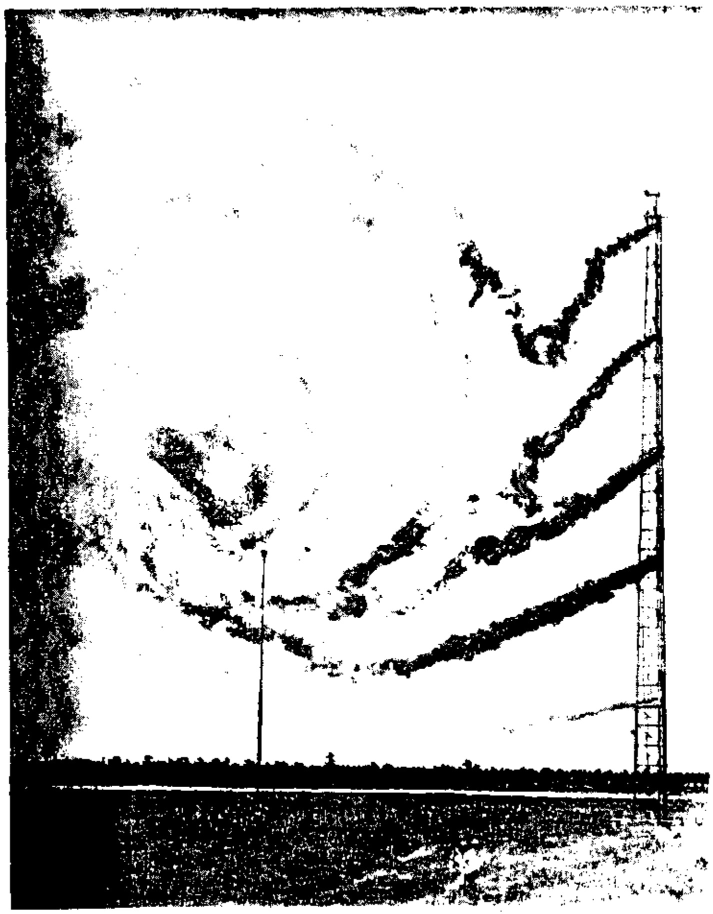


FIGURE 2. Typical Vortex.

6. INDUCED ROLL. A serious wake encounter could result in structural damage. However, the primary hazard is loss of control because of induced roll. Aircraft intentionally flown directly up the core of a vortex during flight tests tended to roll with that vortex. The capability of counteracting this roll depends on the span and counter control responsiveness of the encountering aircraft.

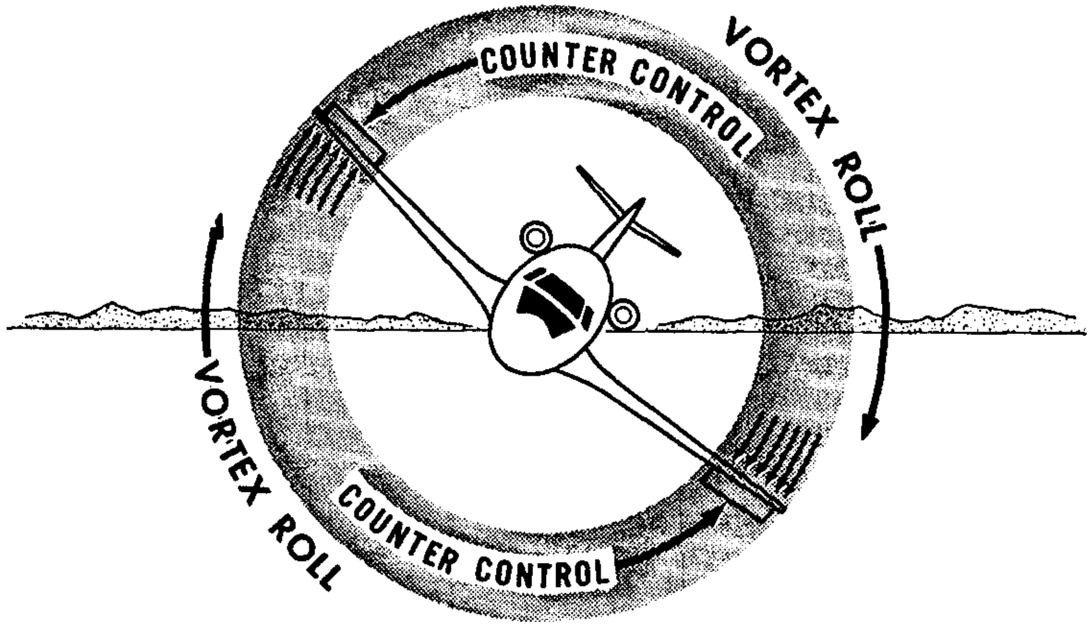


FIGURE 3. Induced Roll.

Where the wing span and ailerons of larger aircraft extend beyond the vortex, counter control is usually effective and the induced roll is minimal. If the ailerons of a short span aircraft were wholly within the vortex, its counter control effectiveness would be substantially reduced. If the vortex strength were to exceed the counter control capability of the encountering aircraft, the induced roll could not be stopped. The significant factor in induced roll is the RELATIVE SPAN of the encountering aircraft. The wake of the large jets requires the respect of all pilots.

Pilots of short span aircraft must be especially alert to vortex situations even though their aircraft is one of the high-performance type.

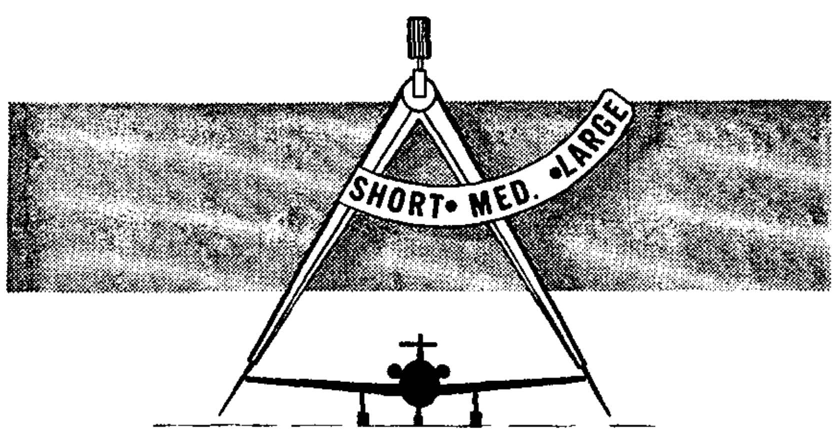


FIGURE 4. Relative Span.

7. VORTEX CHARACTERISTICS. Trailing vortex wakes have certain characteristics which a pilot can use in visualizing the location and avoiding it.

a. Vortex generation starts with rotation when the nose wheel lifts off and ends when the nose wheel touches down on landing.

Pilots should note the rotation or touchdown point of the preceding aircraft.

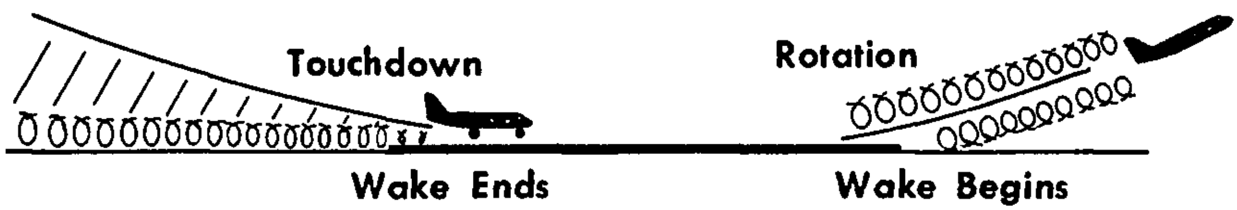


FIGURE 5.

b. The vortex circulation is outward, upward, and around the wing tip when viewed from either ahead or behind the aircraft. Tests with heavy aircraft have shown that the diameter of the vortex core ranges from 25 to 50 feet, but the field of influence is larger (see Figure 2). The vortices stay close together (about 3/4 of the span) until dissipation. In view of this, if persistent vortex turbulence is encountered, a slight lateral change in flight path will usually avoid it.

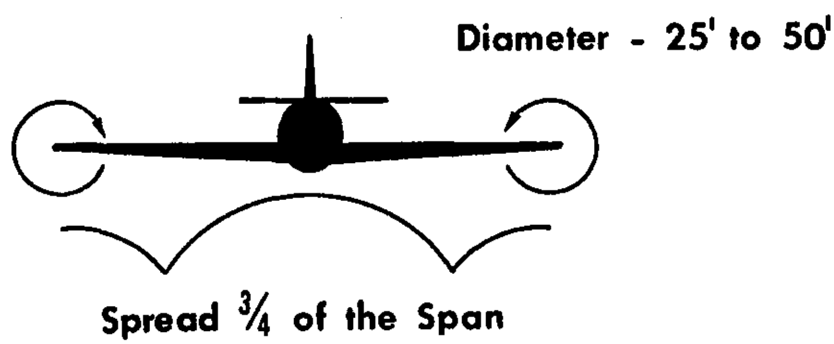


FIGURE 6.

c. Flight tests have shown that the vortices from heavy jets start to sink immediately at about 400 to 500 feet per minute. They tend to level off about 800 to 900 feet below the generator's flight path. Vortex strength diminishes with time and distance behind the generating aircraft. Atmospheric turbulence hastens breakup. Residual choppiness remains after vortex breakup.

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

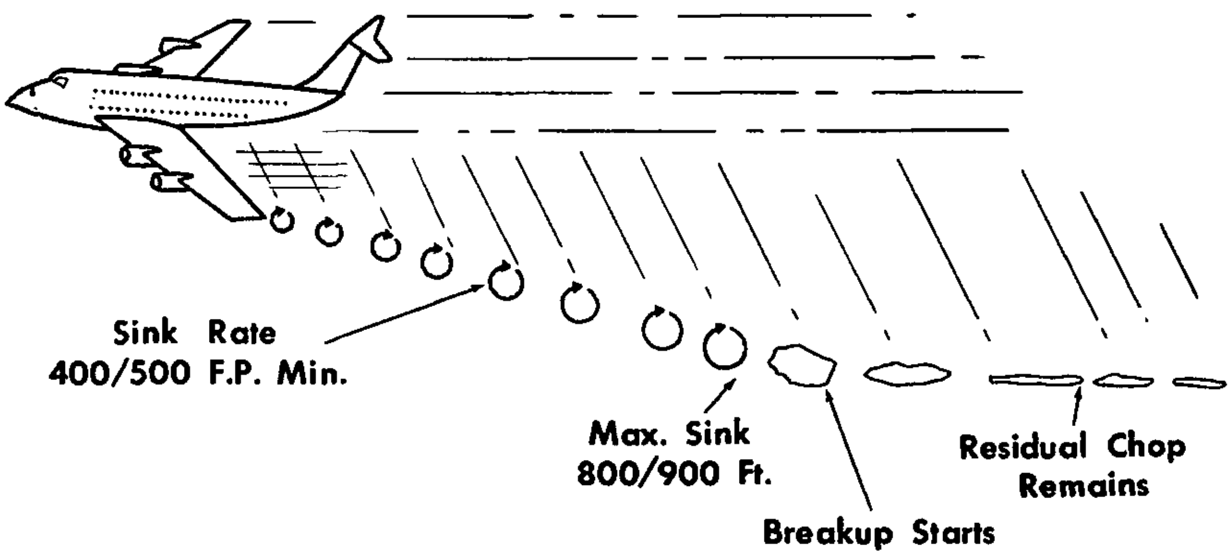
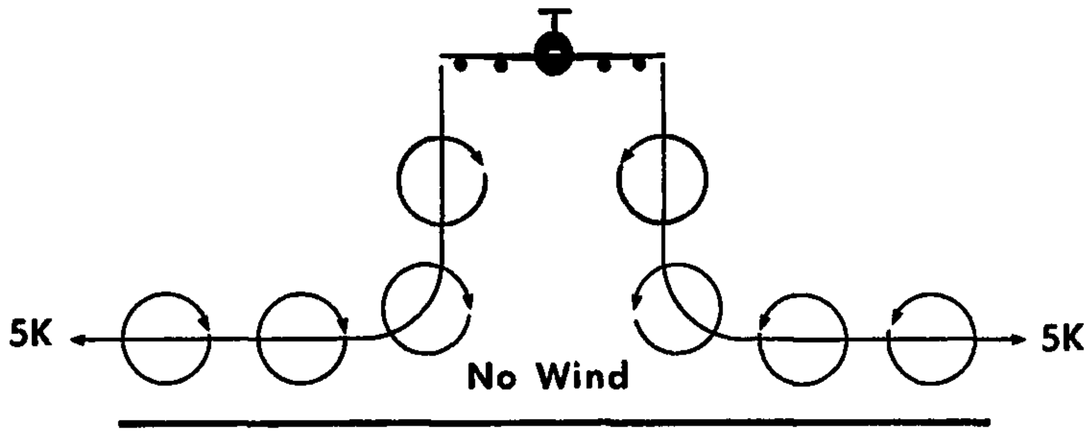


FIGURE 7.

d. When the vortices sink into ground effect, they tend to move laterally outward over the ground at a speed of about 5 knots. (Figure 8.)

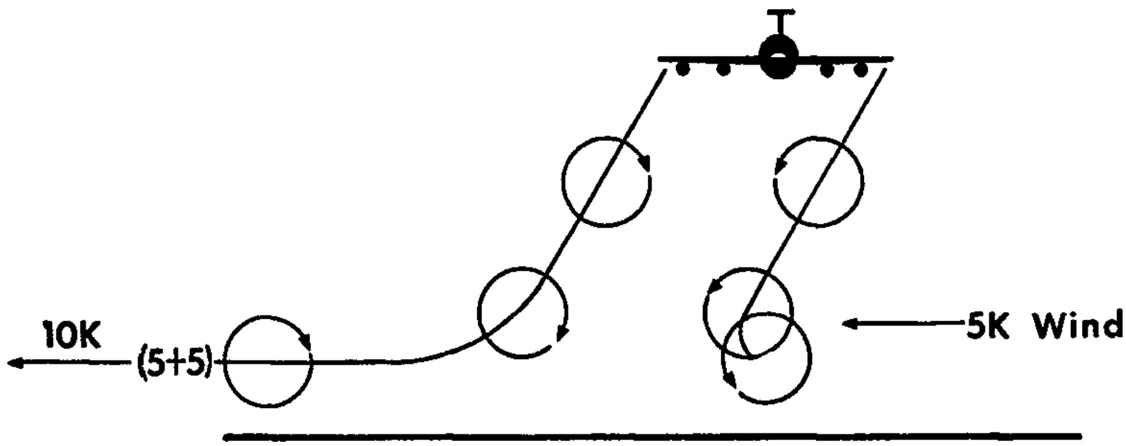
A crosswind component will decrease the lateral movement of the upwind vortex and increase the movement of the downwind vortex (Figure 9). This may result in the upwind vortex remaining in the touchdown zone or hasten the drift of the downwind vortex toward a parallel runway. Similarly, a tail wind condition can move the vortices of the preceding aircraft forward into the touchdown zone (Figure 10).

Pilots should be alert to heavy jets upwind from their flight path.



Vortex Movement in Ground Effect - No Wind

FIGURE 8.



Vortex Movement in Ground Effect with Cross Wind

FIGURE 9.

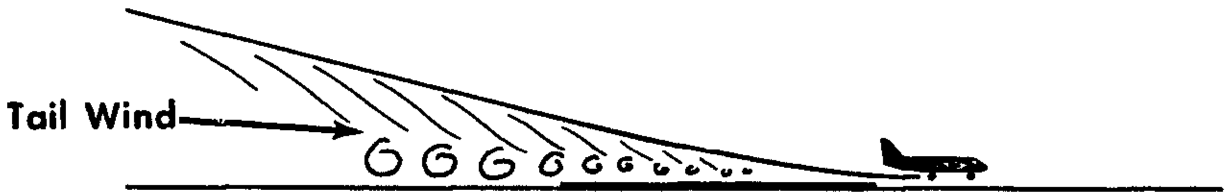


FIGURE 10.

8. OPERATIONAL PROBLEM AREAS. A wake encounter is not necessarily hazardous. It may be only two bumps, one for each vortex, as the wake is crossed. 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 buffeting and induced roll increases when the encountering aircraft's heading is generally aligned with the vortex trail.

AVOID ENCOUNTERS BELOW AND BEHIND THE GENERATING AIRCRAFT, ESPECIALLY AT LOW ALTITUDE WHERE EVEN A MOMENTARY WAKE ENCOUNTER COULD BE HAZARDOUS.

Pilots should be particularly alert to calm wind conditions and situations where the vortices:

a. Remain in the touchdown area.

b. Drift downwind to a parallel runway.

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

d. Sink into the traffic patterns for other airports.

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

Pilots should visualize the location of the vortex trail and use proper vortex avoidance procedures to achieve safe operation in a mixed traffic environment. It is equally important that pilots of medium and large aircraft plan their flight paths to minimize vortex exposure to other aircraft.

9. VORTEX AVOIDANCE PROCEDURES. Under certain conditions, airport traffic controllers apply procedures for separating other aircraft from large and heavy turbojets. They will also provide VFR aircraft with whom they are in communication and which in the tower's opinion may be adversely affected by potential wake turbulence from a heavy jet, the position, altitude, and direction of flight of the heavy jet 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 heavy jet - same runway:

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

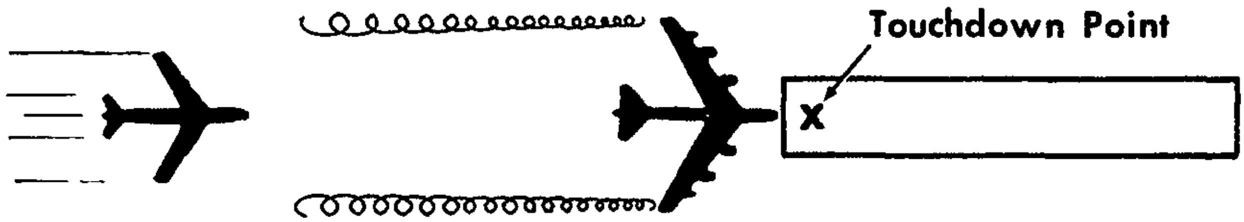


FIGURE 11.

b. Landing behind a heavy jet - when parallel runway is closer than 2,500 feet:

Note wind for possible vortex drift to your runway--request upwind runway if practical. Stay at or above the heavy jet's final approach flight path--note his touchdown point--land beyond a point abeam his touchdown point.

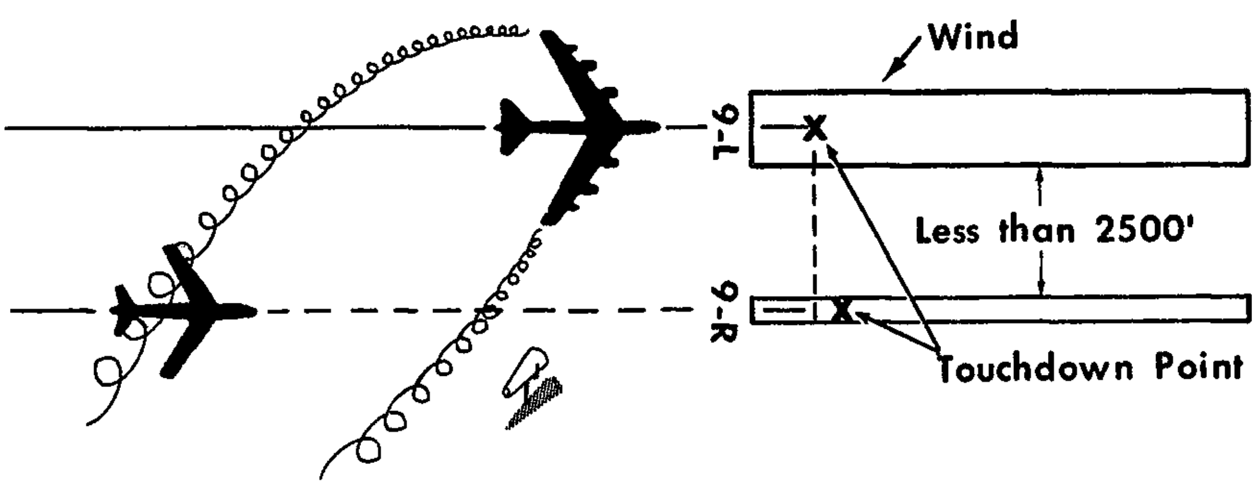


FIGURE 12.

c. Landing behind a heavy jet - crossing runway:

Cross above the heavy jet's flight path.

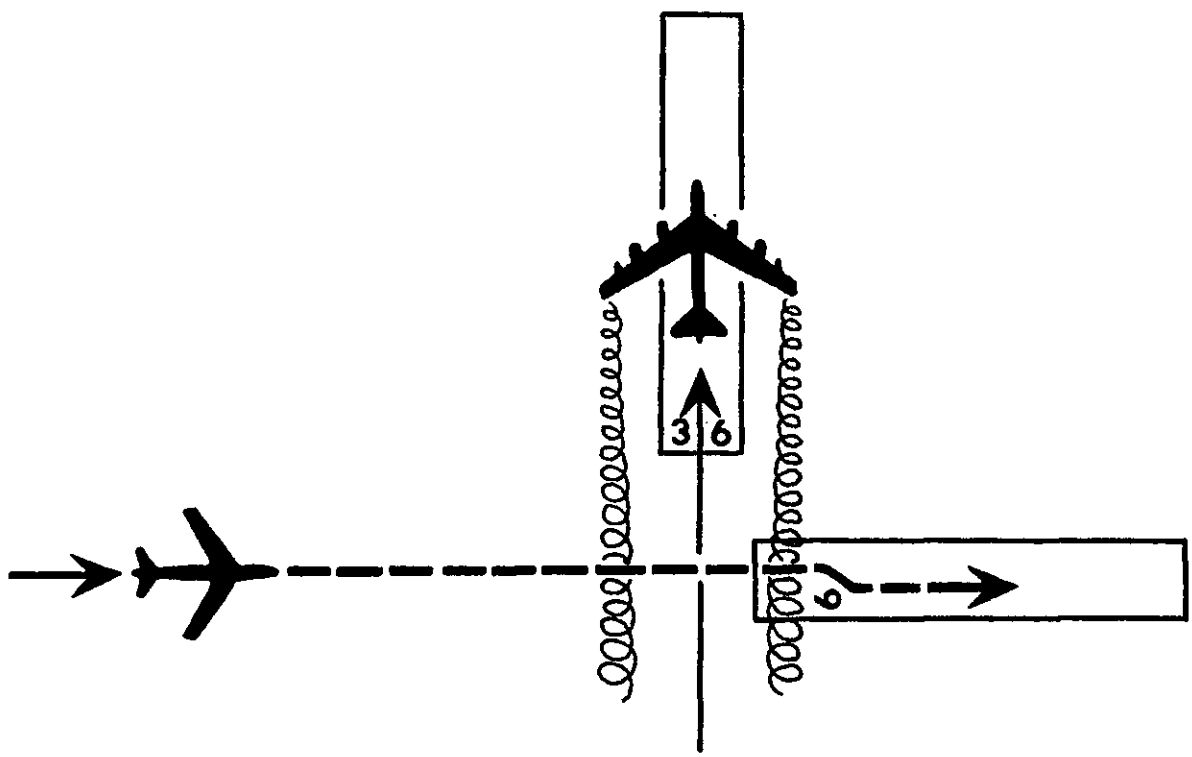


FIGURE 13.

d. Landing behind a departing heavy jet - same runway:

Note heavy jet's rotation point--land well prior to rotation point.

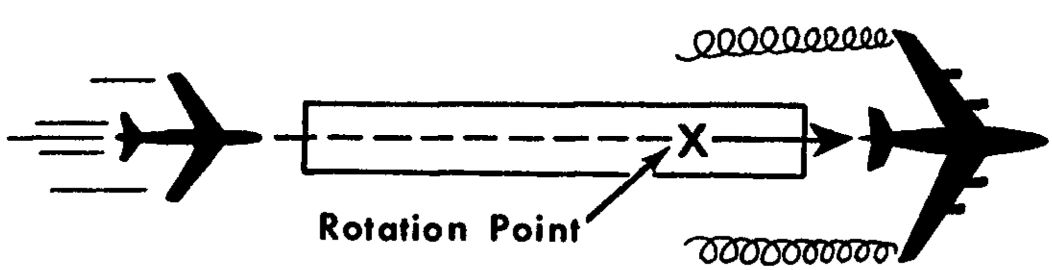


FIGURE 14.

e. Landing behind a departing heavy jet - crossing runway:

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

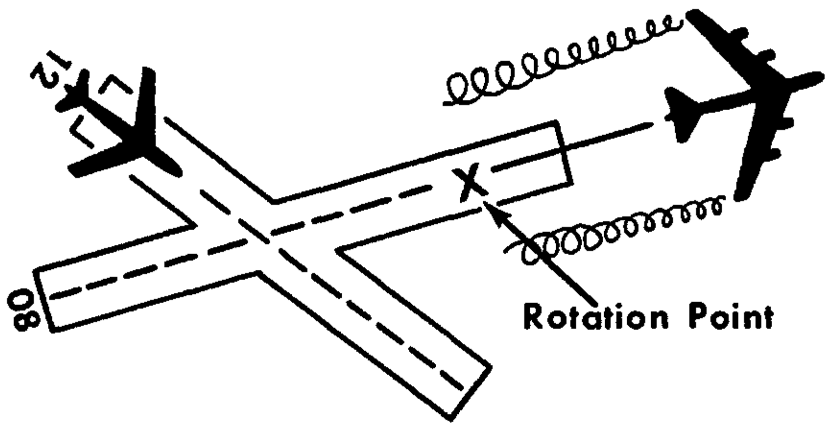


FIGURE 15.

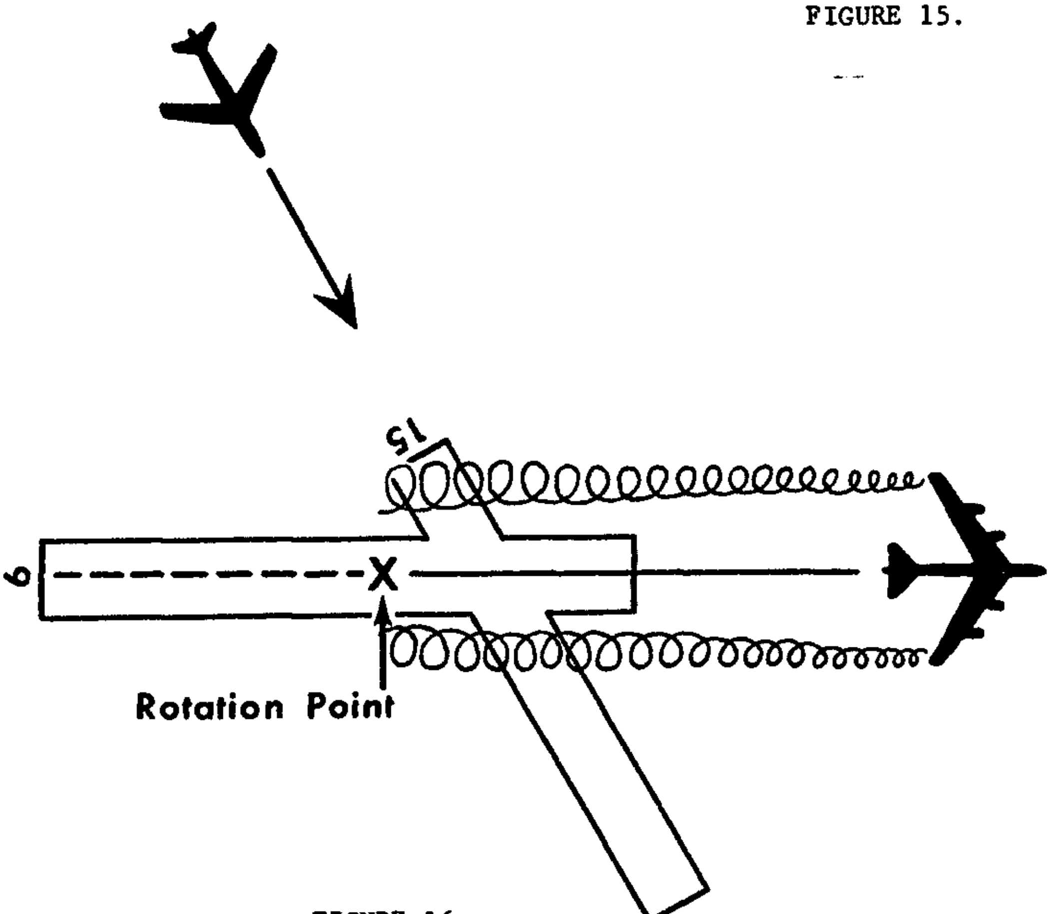


FIGURE 16.

f. Departing behind a heavy jet:

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

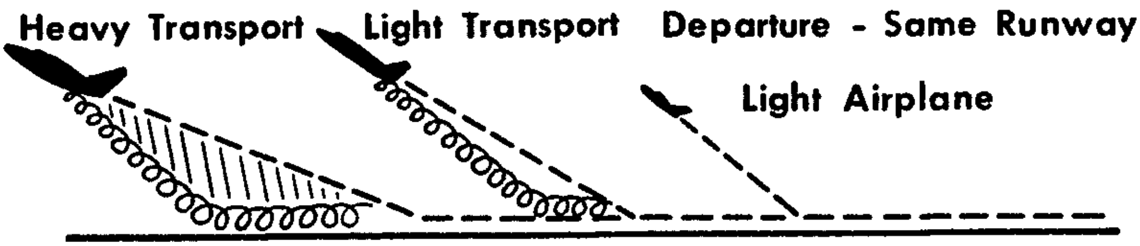


FIGURE 17.

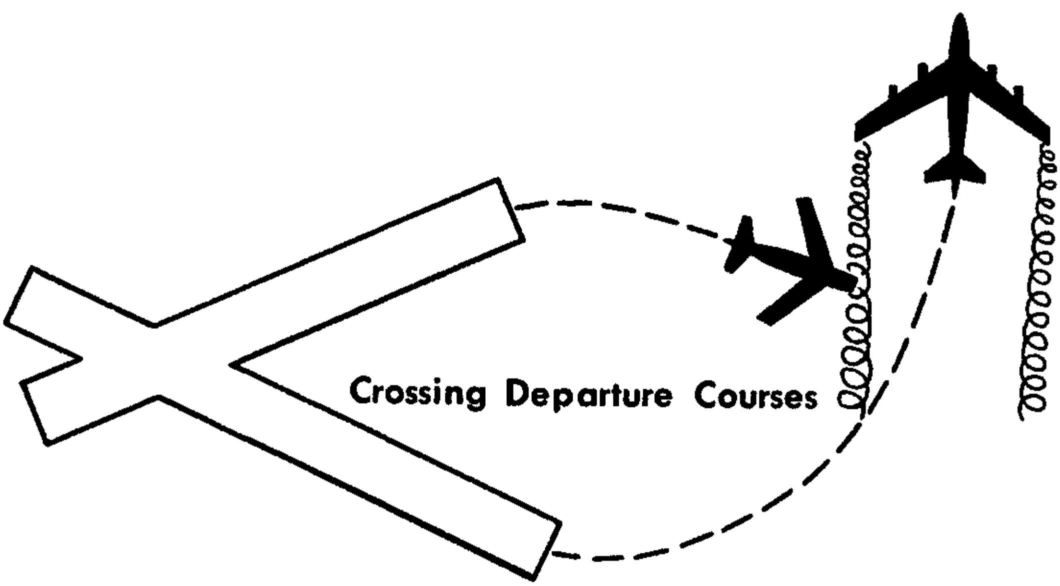


FIGURE 18.

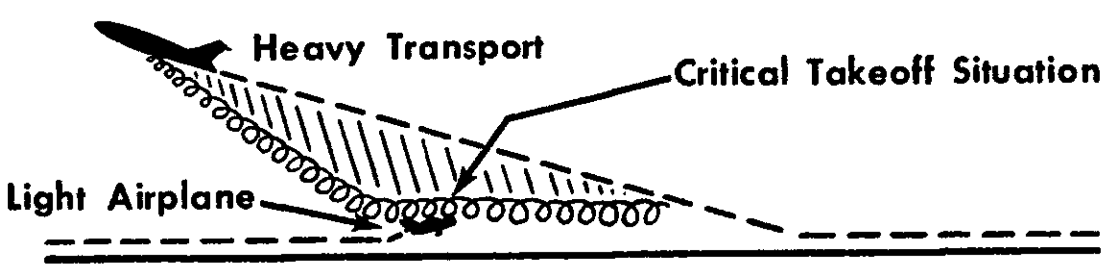


FIGURE 19.

g. Intersection takeoffs - same runway:

Be alert to adjacent heavy jet operations particularly upwind of your runway. If intersection takeoff clearance is received, avoid subsequent heading which will cross below a heavy jet's path.

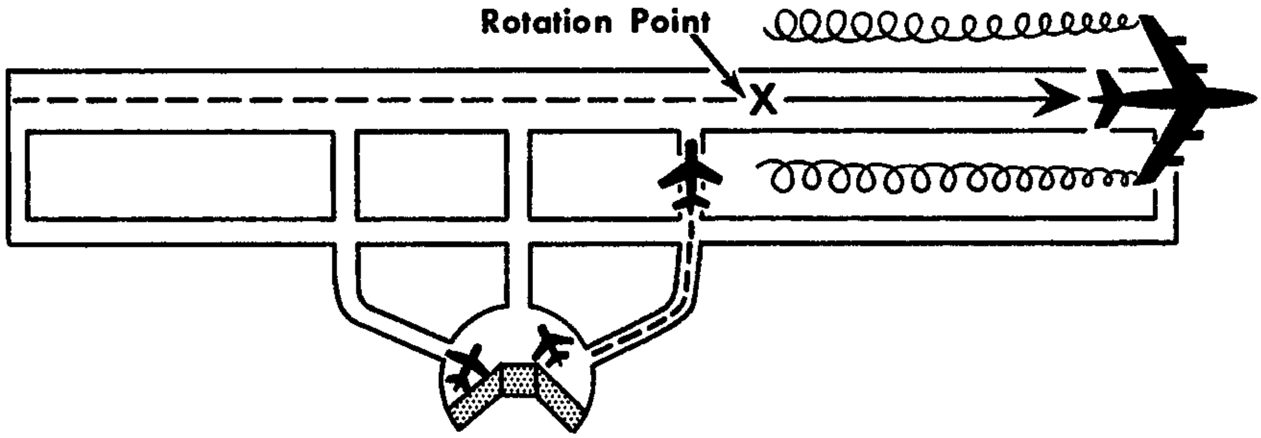


FIGURE 20.

h. Enroute VFR - (thousand-foot altitudes plus 500 feet).

Avoid flight below and behind a heavy jet's path. If a heavy jet is observed above you on same track (same or opposite direction) adjust your position laterally, preferably upwind.

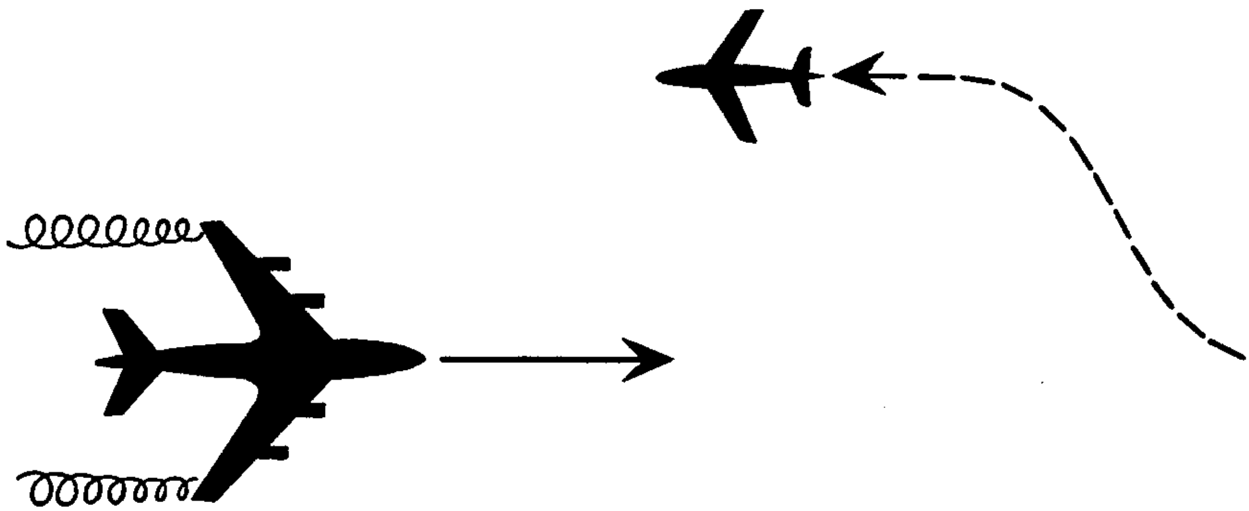


FIGURE 21.

10. HELICOPTERS. A hovering helicopter generates a downwash from its main rotor(s) similar to the prop blast of a conventional aircraft. In forward flight, this energy is transformed into a pair of trailing vortices similar to wing-tip vortices. Pilots of small airplanes and helicopters should avoid both the vortices and downwash of a heavy helicopter.

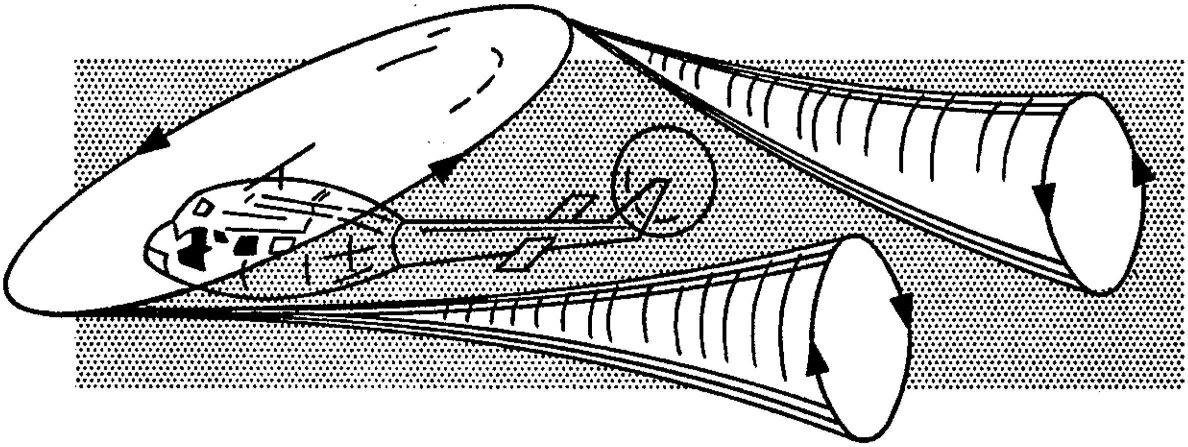


FIGURE 22. Helicopter Vortices.

11. JET ENGINE BLAST. During ground operations, jet engine blast (thrust stream turbulence) can cause damage and upsets if encountered at close range. It is recommended that light aircraft remain at least 200 feet behind a jet operating its engines at idle speed - 400 feet behind a taxiing jet - 1,000 feet from a jet taking off. Engine thrust velocities generated by large jet aircraft during initial takeoff roll and the drifting of the turbulence in relation to the crosswind component dictate the desirability of lighter aircraft awaiting takeoff to hold well back of the runway edge or taxiway hold line; also, the desirability of aligning the aircraft to face the possible jet engine blast movement. The FAA has established new standards for location of taxiway hold lines at airports served by air carriers as follows:

"Locate all taxiway holding lines such that the distance from the runway structural pavement edge to the taxiway holding line is at least equal to the greater of the following: (1) 100 feet or (2) the wing span of the largest airplane that is expected to use the runway."

(See Figure 23.)

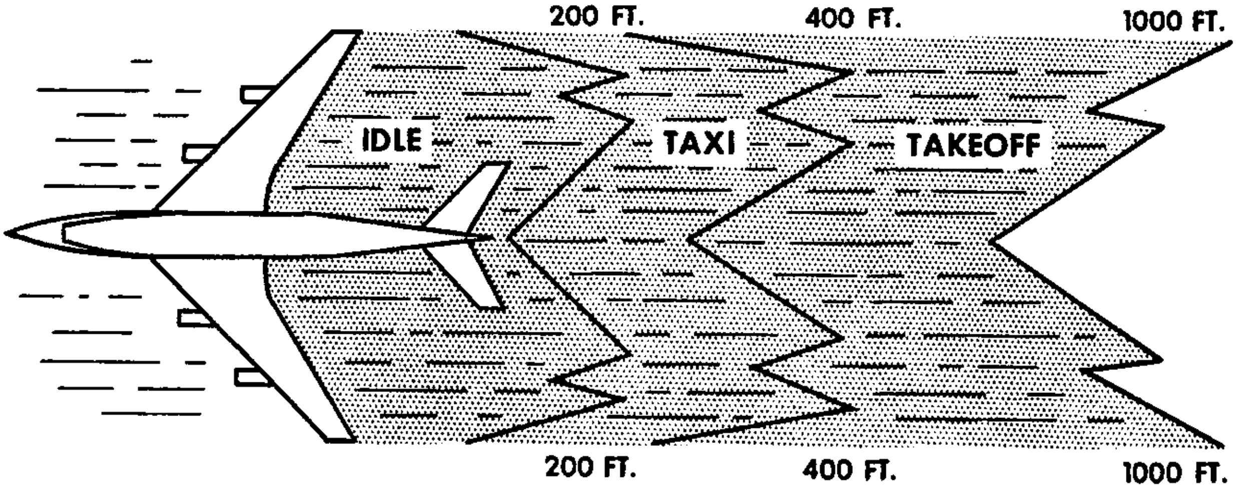


FIGURE 23. Jet Blast Envelope.

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 are equal in importance to traffic avoidance.

Acting Director, Flight Standards Service

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