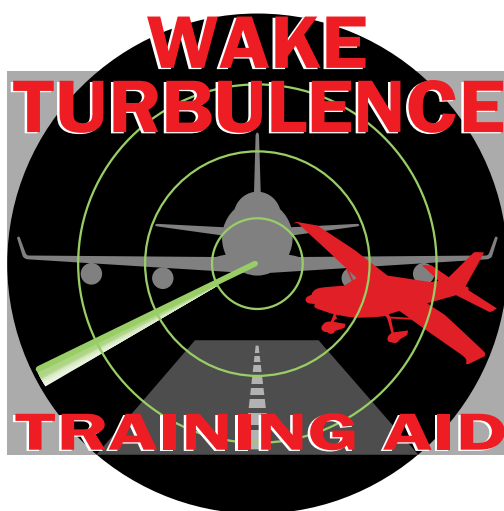


2

Pilot and Air Traffic Controller Guide to Wake Turbulence



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Pilot and Air Traffic Controller Guide to Wake Turbulence

2

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Pilot and Air Traffic Controller Guide to Wake Turbulence

2

2.0 Introduction

The Pilot and Air Traffic Controller Guide to Wake Turbulence is one part of the Wake Turbulence Training Aid. The other parts include Section 1, Wake Turbulence - Overview for Training Aid Users; Section 3, Example Pilot and Air Traffic Controller Wake Turbulence Training Program; Section 4, Wake Turbulence Training Aid - Background Data, and a video.

2.0.1 Preview

This Pilot and Air Traffic Controller Guide to Wake Turbulence is a comprehensive document covering all the factors leading to a shared awareness and understanding of wake turbulence. A review of the history of wake-turbulence studies, from the introduction of turbo-jet aircraft to today's environment, is the starting point. A description of typical accidents and incidents allows a look at trends and lessons learned from history. With history as a basis, a thorough description is given of the wake-turbulence hazard. This includes the formation, effects, and dissipation of the wake vortex phenomenon. A description is given of our ability to predict, detect, and measure the wake-turbulence hazard. This includes future planned improvements in these areas.

Given our knowledge of wake turbulence, the best solution is to avoid the wake-turbulence hazard. This document reviews the existing avoidance guidance and both air traffic control and pilot responsibilities. A discussion is offered regarding the difficulty for pilots to visually maintain separation and offers rec-

ommended techniques. A brief discussion of pilot responses to encountering wake turbulence precedes a section that stresses the necessary cooperation of pilots and air traffic controllers to safely and efficiently manage the busy airport environment and avoid wake-turbulence encounters. Lastly, the importance of air traffic control considerations associated with assisting pilots in avoiding wake turbulence is discussed.

2.0.2 The Goal

The goal of the Wake Turbulence Training Aid is to reduce the number of wake-turbulence related incidents and accidents by improving the pilot's and air traffic controller's decision making and situational awareness through increased and shared understanding and heightened awareness of the factors involved in wake turbulence. This can be accomplished by the application of knowledge, techniques and training applied to everyday operations.

2.0.3 Participants and Review Process

The Wake Turbulence Training Aid is the result of many hours of effort on the part of a large industry team. This team consisted of: Air Line Pilots Association, Air Traffic Control Association, Airbus Industrie, Airbus Service Company, Inc., Allied Pilots Association, American Airlines, Aircraft Owners and Pilots Association, Air Transport Association, Boeing Commercial Airplane Group, Delta Air Lines, Inc., Federal Aviation Administration, Flight Safety Foundation, General Avia-

tion Manufacturers Association, Hydrolin Research Corporation, Independent Pilots Association, International Civil Aviation Organization, McDonnell Douglas Aircraft Company, National Aeronautics and Space Administration, National Air Traffic Controllers Association, Inc., National Air Traffic Services (CAA), National Air Transportation Association, Inc., National Business Aircraft Association, National Transportation Safety Board, Regional Airline Association, Southwest Airlines, The Communications Company, U.S. Department of Transportation, and United Airlines.

The team worked on this project over a period of nine months. During this period the Wake Turbulence Training Aid and associated video was developed. In all, a total of four review cycles were conducted, during which the comments and recommendations of all participants were considered for inclusion in the final material. Three industry review meetings were held along with a final draft/final video industry buy-off process. The Federal Aviation Administration is responsible for the final reproduction and distribution of the Wake Turbulence Training Aid. As significant material is developed and changes are required to this document, a review will be conducted by the industry team and appropriate updating of the material will be developed and distributed.

2.1 Objectives

The objectives of the Pilot and Air Traffic Controller Guide to Wake Turbulence are to summarize and communicate key wake-turbulence related information relevant to pilots and air traffic controllers. It is intended to be provided to air traffic controllers and pilots during academic training and to be retained for future use.

The Pilot and Air Traffic Controller Guide to Wake Turbulence will:

- educate pilots and air traffic controllers on wake turbulence and avoidance of the phenomenon.
- increase the wake turbulence situational awareness of pilots and air traffic controllers (situational awareness being defined as an accurate perception by pilots and air traffic controllers of the factors and conditions currently affecting the safe operation of the aircraft and the crew).
- provide usable information to develop a ground training program.

The most important success tool available today to pilots and air traffic controllers to reduce wake-turbulence accidents and incidents is awareness and education. One of the objectives of this training aid is to educate pilots and air traffic controllers on wake turbulence and avoidance of the phenomena. This can be done by updating the basic understanding of wake turbulence to help reduce and clear up common misconceptions and generate respect for the hazard. This education will expand the awareness of pilots and air traffic controllers of their mutual involvement in the avoidance of wake turbulence. Additionally, education will generate baseline knowledge for instructors and those people involved with developing training programs.

Another clear objective is to increase the wake-turbulence situational awareness of pilots and air traffic controllers. This aid will provide recommendations to improve situational awareness involving wake turbulence and techniques for detection, avoidance and recovery. This should lead to shared awareness and cooperation among air traffic controllers and pilots. Improved situational awareness

will better prepare pilots and air traffic controllers for future improvements and new tools to cope with wake turbulence.

Lastly, this Pilot and Air Traffic Controllers Guide to Wake Turbulence aims to provide usable information for the development of ground training programs. There are many sources of information about wake turbulence. This aid attempts to compile those sources to provide information for training developers. Since simulation capability is limited, the ground training material is developed into written modules, exams, and a stand-alone video.

2.2 Historical Examination of the Wake-Turbulence Hazard

Wake turbulence is a natural by-product of powered flight, but was not generally regarded as a serious flight hazard until the late 1960s. Upsets or turbulence encounters associated with other aircraft were usually accredited to “propwash” and later on, with “jet wash.” Interest in this phenomenon greatly increased with the introduction of large, wide-body turbojet aircraft during the late 1960s and a concern about the impact of greater wake turbulence. This was the impetus to conduct research to gain additional information and determine what safety considerations were necessary as more and more large aircraft entered the industry fleets.

An investigation of the wake-turbulence phenomenon, conducted by Boeing in mid 1969 as part of the FAA test program, included both analysis and limited flight test and produced more detailed information on wake vortices. The flight tests provided a direct comparison between the B-747 and a representative from the then current jet fleet, a B-707-320C. The smallest Boeing jet transport, the B-737-100, was used as the primary wake-turbulence probing aircraft along with an F-86 and the NASA CV-990. Smoke generating

towers were also used to observe the wake turbulence generated by aircraft as they flew by. Several observations were made.

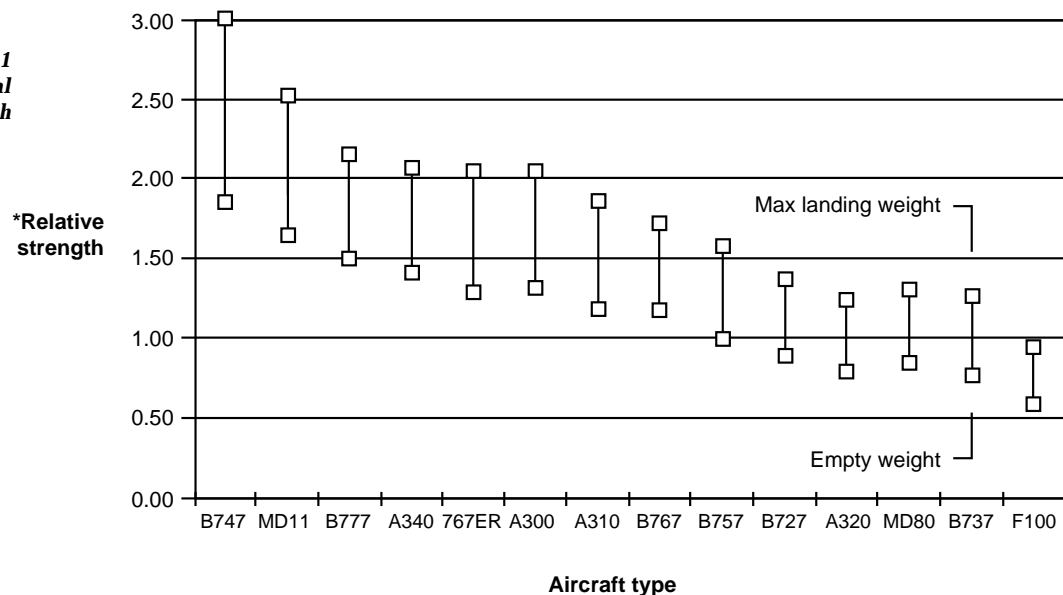
- The strength of the wake turbulence is governed by the weight, speed and wingspan of the generating aircraft.
- The greatest strength occurs when the generating aircraft is heavy, at slow speed with a clean wing configuration.

Initial flight tests produced sufficient information about the strength, duration and movement of wake turbulence to come to conclusions and recommendations on how to avoid it. The wake was observed to move down initially and then level off. It was never encountered at the same flight level as the generating aircraft or more than 900 feet below the generating aircraft. Therefore, a following aircraft could avoid the wake turbulence by flying above the flightpath of the leading aircraft. While this can be accomplished in visual conditions, an alternative was developed for instrument meteorological conditions. Aircraft were placed into categories determined by their gross weight. It was noted that a division based on the wingspan of the following aircraft was a more technically correct way to establish categories; however, it did not appear to be an easily workable method. Since there is a correlation between aircraft gross weight and wingspan, gross weight was selected as a means of categorizing aircraft and wake-turbulence strength. Minimum radar-controlled wake-turbulence separation distances were established for following aircraft. The separation distances depend on the weight of both the leading and following aircraft. Adjustments in separation distances were made as more information on the wake-turbulence phenomenon was gained during the 1960s, 1980s and 1990s, but the basic concept of using aircraft weights remained constant.

Initially, the turbojets that were being produced fit cleanly into distinct categories with logical break points. For example, heavy aircraft such as the Boeing B-747, Lockheed L-1011 and the Douglas DC-10 were clearly in a class by themselves. There were very few regional or business support size aircraft. Today, there is almost a continuum of aircraft sizes as manufacturers developed the “aircraft family” concept and produced many new transport and corporate aircraft. With

improved technology, heavier aircraft are produced with better aircraft performance allowing them the use of shorter runways that previously could only be used by smaller aircraft. Additionally, a hub and spoke mix of regional aircraft with heavy jets, coupled with an already active private and recreational aircraft population, results in a range of wake-turbulence strengths produced and potentially encountered by a large variety of aircraft, as illustrated below (Figure 2.2-1).

Figure 2.2-1
Calculated initial
vortex strength



* Relative strength is the strength variation between maximum landing weight and empty weight relative to a B-737 of a weight midway between its maximum weight and its empty weight.

The wake-turbulence separation criteria, while necessary, are currently a limiting factor in several airport capacities. The FAA is working with NASA to develop and demonstrate integrated systems technology for addressing separation criteria. The thrust of the work is to develop wake-turbulence prediction capability, sensors for detecting wake-turbulence hazards on final approach and an automated system to maximize operating efficiency while maintaining safety standards.

The effort to gain more information about wake turbulence continues.

2.3 Review of Accidents and Incidents

National Transportation Safety Board data show that between 1983 and 1993, there were at least 51 accidents and incidents in the United States that resulted from probable encounters with wake turbulence. In these 51 encounters, 27 occupants were killed, 8 were seriously injured, and 40 aircraft were substantially damaged or destroyed. Numerous other encounters have been documented in the NASA Aviation Safety Reporting System (ASRS). Since participation in ASRS is voluntary, the statistics probably represent a lower measure of the true number of such events which occurred. The following are accounts of real events.

1. A pilot of a medium transport (60,000+ pounds) was told to expedite the takeoff behind a large transport (150,000+ pounds) on runway 32L at Chicago. He began his takeoff roll as the large transport rotated. The large transport went straight ahead and the pilot of the medium transport was instructed to turn to 180 degrees. He started the turn at 300 feet AGL with 15 degrees of bank angle. The bank angle violently increased to 30 degrees from the apparent wake turbulence of the large transport.

The takeoff was initiated about 30 or 40 seconds after the first aircraft.

2. A Cessna Citation 550 crashed while on a visual approach. The two crew members and six passengers were killed. Witnesses reported that the aircraft suddenly and rapidly rolled left and then contacted the ground while in a near-vertical dive. Recorded ATC radar data show that at the point of upset, the Citation was about 2.78 nautical miles (about 74 seconds) behind a B-757. The flightpath angle of the Citation was 3 degrees and the flightpath angle of the B-757 was 4.7 degrees. Standard IFR separation (greater than 3 nautical miles) was provided to the pilot of the Citation. About 4.5 minutes prior to the accident while following the B-757 at a distance of 4.2 nautical miles, the pilot requested and was cleared for a visual approach behind the B-757. After the visual approach clearance was acknowledged, the speed of the Citation increased while the speed of the B-757 decreased in preparation for landing. The controller informed the Citation pilot that the B-757 was slowing and advised the pilot that a right turn could be executed to increase separation.

Although radar data indicate that, at any instant, the Citation was at least 600 feet higher than the leading B-757 during the last 4 miles of the approach, the flightpath of the Citation was actually at least 300 feet below that of the B-757.

3. The pilot of a Cessna 182 was executing a visual flight rules approach to runway 32 at Salt Lake City International Airport, Utah. The pilot reported that he was instructed by ATC to proceed "direct to the numbers" of runway 32 and pass behind a "Boeing" that was on final approach to runway 35. The Cessna pilot reported that while on final approach, the aircraft experienced a "burbles," and then the nose pitched up and the aircraft suddenly rolled 90 degrees to the right. The pilot immediately put in full-left deflection of rudder and aileron and full-down elevator in an attempt to level the aircraft and to get the nose down. As the aircraft began to respond to the correct attitude, the pilot realized that he was near the ground and pulled the yoke

back into his lap. The aircraft crashed short of the threshold of runway 32, veered to the northeast, and came to rest in the approach end of runway 35. The pilot and the two passengers suffered minor injuries, and the aircraft was destroyed. The wind was 5 knots from the south.

The approach ends of runways 32 and 35 are about 560 feet apart. Radar data show that the Cessna was at an altitude of less than 100 feet above ground level (AGL) when it crossed the flightpath of the B-757. The B-757 had passed the crossing position about 38 seconds prior to the Cessna 182.

4. A Gulfstream IV departed New Jersey on a routine night trip to Florida with a crew of 3 and 2 passengers. The weather was clear with unlimited visibility and smooth air. During a slow descent for landing at approximately Flight Level 250, ATC advised the pilot that he might see traffic crossing from right to left. The Gulfstream pilot sighted the traffic far ahead. At about 15,000 feet and 300 knots, the Gulfstream pilot reported that he felt like he had "hit a 20 foot thick concrete wall at 300 knots." The flight attendant and passengers were injured. The passengers were jettisoned to the ceiling and slammed to the floor. The aircraft was checked for damage and landed uneventfully.

5. A McDonnell Douglas MD-88 was executing a visual approach while following a B-757 to the airport. The crew of the MD-88 reported that the aircraft suddenly rolled right about 15 degrees and the pilot rapidly deflected both the wheel and rudder pedal to correct the uncommanded roll. Data from the digital flight data recorder indicate that at about 110 feet AGL the roll angle reached 13 degrees right wing down and the ailerons and rudder were deflected about one-half of full travel, 10 degrees and 23 degrees respectively. The crew regained control and the approach was continued to an uneventful landing. Recorded radar data show that at the point of upset, the MD-88 was about 2.5 nautical miles (65 seconds) behind the Boeing 757 while the flightpath of the MD-88 was slightly below that of the B-757. The flightpath angle of both aircraft was 3 degrees.

The MD-88 flight crew had been issued a visual approach clearance when the aircraft was 4.5 nautical miles from the leading aircraft. However, the separation quickly reduced to 2.5 nautical miles. The MD-88 flight crew told investigators that they thought they had a 4 nautical mile separation at the time of the encounter.

6. An Israel Aircraft Industries Westwind crashed while on a visual approach. The two crew members and three passengers were killed. Witnesses reported that the aircraft rolled and the cockpit voice recorder (CVR) data indicate that the onset of the event was sudden. The aircraft pitch attitude was about 45 degrees nose down at ground contact. Recorded radar data show that at the point of upset, the Westwind was about 1200 feet above mean sea level and 3.5 nautical miles from the runway. The Westwind was about 2.1 nautical miles (60 seconds) behind a B-757 and on a flightpath that was about 400 feet below the flightpath of the B-757. The flightpath angle of the Westwind was 3 degrees and the flightpath angle of the B-757 was 5.6 degrees. CVR data indicate that the Westwind pilots were aware they were close to a Boeing aircraft and the aircraft appeared high. They anticipated encountering a little wake and intended to fly one dot high on the glideslope.

While receiving radar vectors to the airport, the crews of both aircraft were flying generally toward the east and would have to make right turns to land to the south. Radar data and ATC voice transcripts show that the Westwind was 3.8 nautical miles northeast of the B-757 when cleared for a visual approach. The Westwind started its right turn from a ground track of 120 degrees while the B-757 ground track remained at about 90 degrees. The resultant closure angle started at 30 degrees and became greater as the Westwind continued its turn. About 23 seconds later, the B-757 was cleared for the visual approach. The average ground speeds of the Westwind and the B-757 were about 200 and 150 knots, respectively. The Westwind was established on course 37 seconds ahead of the B-757. Although the combination of the closure angle and the faster speed of the Westwind reduced sepa-

ration distance from about 3.8 nautical miles to about 2.1 nautical miles in 46 seconds, the primary factor in the decreased separation was the converging ground tracks. The only way the pilot of the Westwind could have maintained adequate separation was to execute significant maneuvers.

Based on radar data, at the time the visual approach clearance was issued, the separation distance was rapidly approaching the 3 nautical miles required for IFR separation. To prevent compromise of the separation require-

ment, the controller would have had to take positive action to change the Westwind's track, or to issue the visual approach clearance and receive confirmation that the pilot accepted the visual approach within 29 seconds.

These cases are extreme wake-turbulence encounters. In all cases, it was possible to avoid the encounters if the pilots and air traffic controllers had sufficient knowledge of wake turbulence and applied proper avoidance procedures and techniques. Hopefully, this training aid will help prevent similar occurrences.

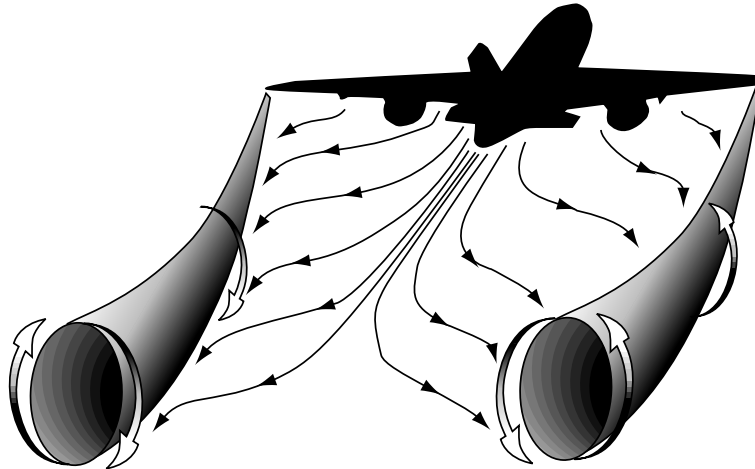
2.4 Description/Characteristics of the Wake-Turbulence Hazard

2.4.1 Wake-Turbulence Formation

The phenomenon that creates wake turbulence results from the forces that lift the aircraft. High pressure air from the lower surface of the wings flows around the wingtips to the lower pressure region above the wings. A

pair of counter-rotating vortices are thus shed from the wings, the right wing vortex rotates counterclockwise, and the left wing vortex rotates clockwise as shown in Figure 2.4-1. This region of rotating air behind the aircraft is where wake turbulence occurs. The strength of the turbulence is predominantly determined by the weight, wingspan and speed of the aircraft.

Figure 2.4-1
Wake-turbulence
formation



The wake turbulence associated with helicopters also results from high pressure air on the lower surface of the rotor blades flowing around the tips to the lower pressure region above the rotor blades. A hovering helicopter generates downwash from its main rotor(s) as

shown in Figure 2.4-1A. In forward flight a pair of downward spiraling vortices are shed from the rotor blades, as shown in Figure 2.4-1B. This region of rotating air below the helicopter is where wake turbulence occurs.

Figure 2.4-1A
Formation of
helicopter wake
turbulence (hover)

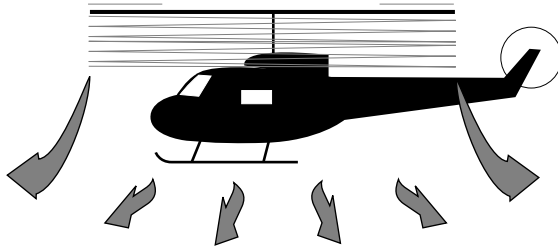
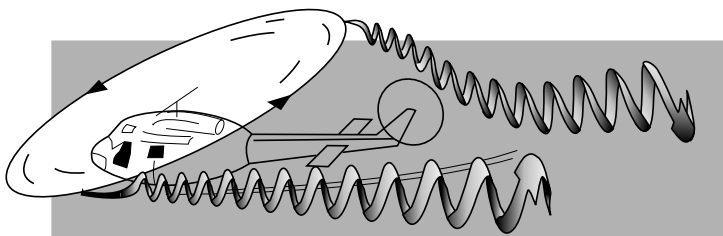


Figure 2.4-1B
Formation of
helicopter wake
turbulence
(forward flight)



The early theories, pre-1970, describing aircraft wake vortex characteristics were very simplistic. They stated that:

- 1) The vortex strength depended on the size, weight, and speed of the aircraft;
- 2) The pair of vortices generally descended after generation and would separate when they approached the ground;
- 3) The vortex motion was substantially affected by the ambient wind.

The lack of field testing prior to 1970, especially of vortices near the ground, precluded an in-depth understanding of vortex behavior, and in particular of the decay process. Now, two decades later, the industry recognizes that there are more factors associated with wake turbulence.

This section briefly summarizes the current knowledge of the behavior of wake vortices. Much has been learned about the characteristics of vortices, but there are still gaps in our understanding. The weight, wingspan and

speed of the aircraft determine the initial strength and motion of the vortices; however, the ambient atmosphere (wind, stability, turbulence, etc.) eventually dictates the motion and decay rate of the vortices.

2.4.2 Velocity Flow Field

The general flow field of a vortex is approximately a circular flow and composed of the following regions:

The core region of the vortex can range from a few inches in diameter to several feet. The outer edge of the core has the maximum rotational velocity of the vortex. The maximum core velocity may exceed 300 ft/sec. The greatest maximum strength occurs when the aircraft has a clean wing.

The outer region of the vortex is characterized by a decreasing velocity profile. As seen in Figure 2.4-2, this region may be as large as 100 feet in diameter.

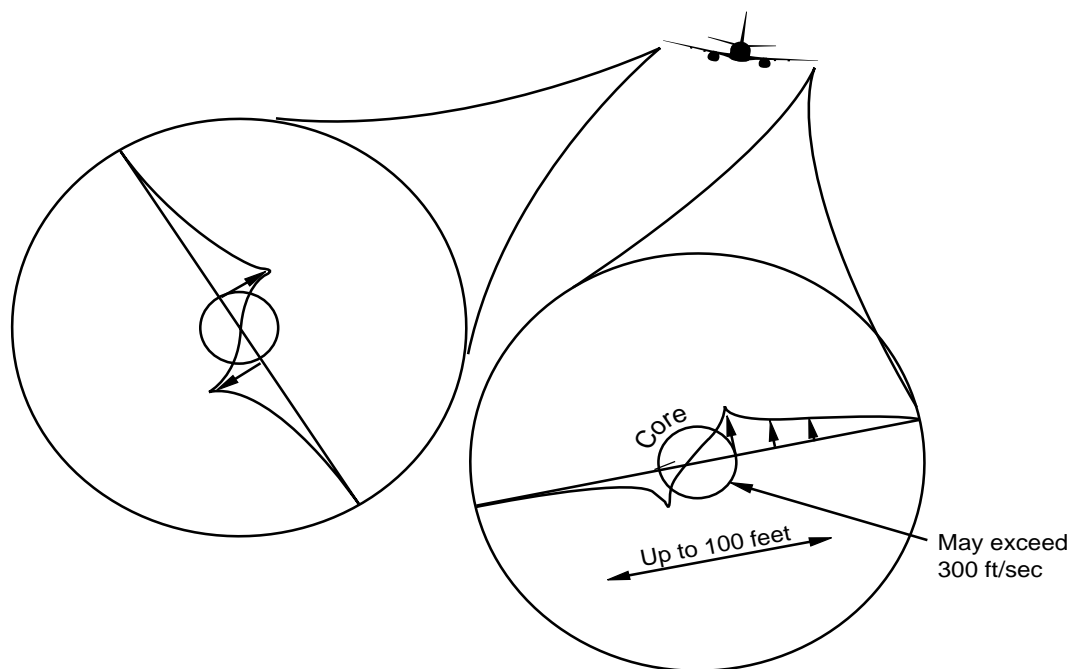


Figure 2.4-2
Velocity profile

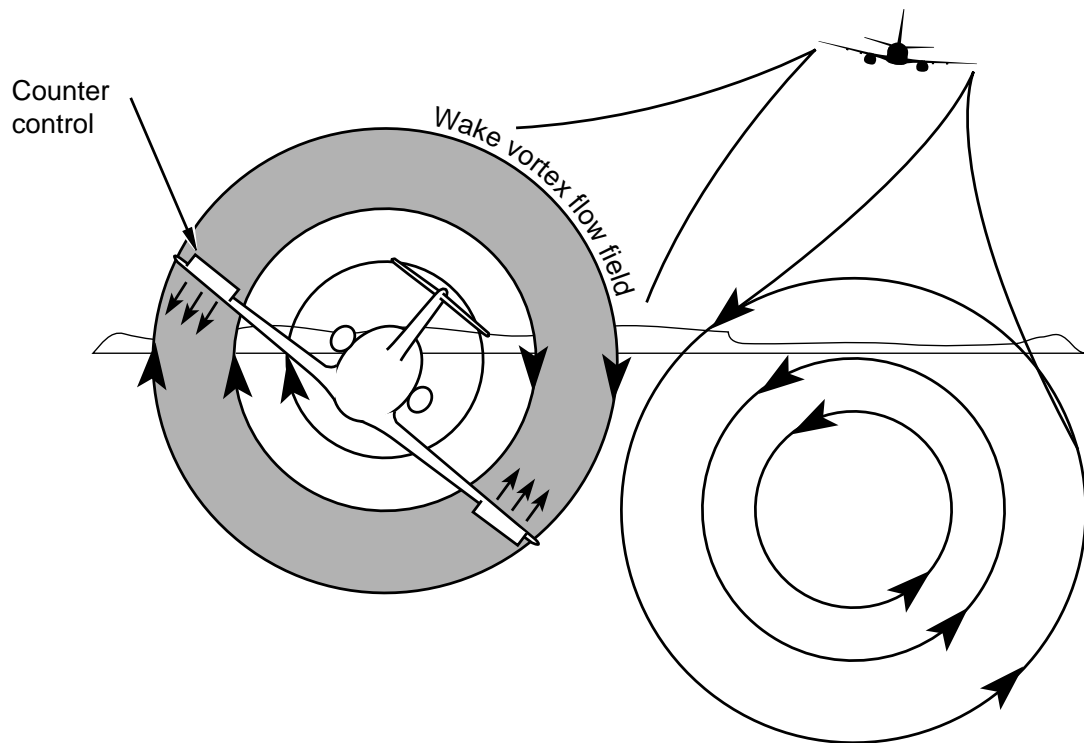
2.4.3 The Hazard (Figure 2.4-3)

The usual hazard associated with wake turbulence is that the induced rolling moment can exceed the roll control of the encountering aircraft. To evaluate the induced rolling moment, the overall profile of the vortex must be combined with the aerodynamic characteristics of the encountering aircraft. During flight tests, aircraft were intentionally flown into the vortex of a heavy aircraft. These tests showed that the capability of an aircraft to counteract the roll imposed by the vortex

primarily depends on the wingspan and the control responsiveness of the encountering aircraft.

Counter control is most effective and induced roll minimal where the wingspan of the encountering aircraft is outside the rotational flow field of the vortex. Counter control is more difficult for encountering aircraft with wingspans that are relatively shorter than that of the generating aircraft. Pilots of short span aircraft and high performance aircraft must be especially alert to vortex encounters.

Figure 2.4-3
Induced roll



The response of an aircraft to the usual wake-turbulence encounter is illustrated below in Figures 2.4-4 thru 2.4-9.

Pilots have also reported “brick wall” encounters where the aircraft experiences a rather abrupt displacement. These encounters seem to occur en route when the encountering aircraft crosses through the wake of the generating aircraft.

When approached from above, the downward flow between the vortices pulls the aircraft through the wake. This creates an uncommanded descent (See Figures 2.4-4 and 2.4-5).

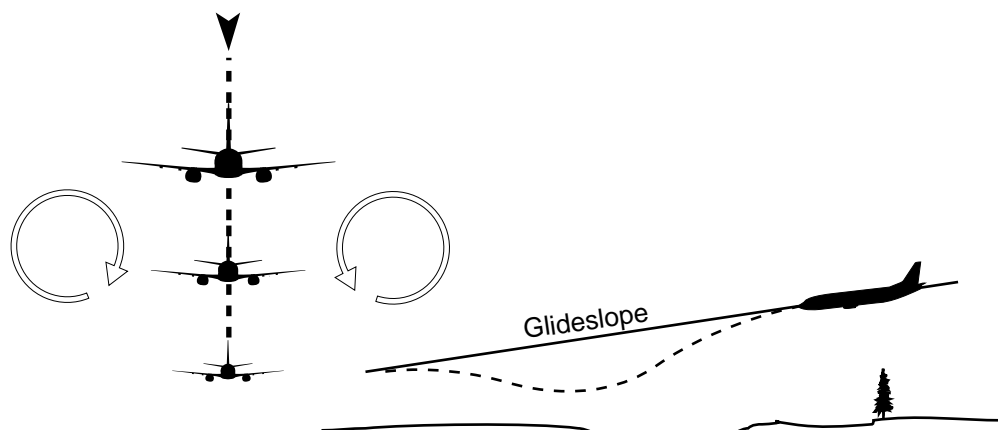


Figure 2.4-4
Aircraft reaction to
wake-turbulence
encounter, approach
from above-center
(rear view
depiction)

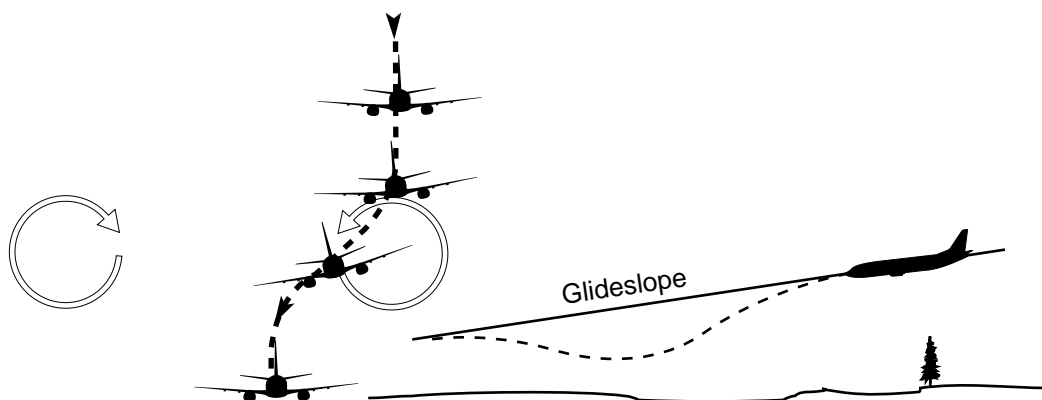


Figure 2.4-5
Aircraft reaction to
wake-turbulence
encounter, approach
from above-right
(rear view
depiction)

When approached from the side, the upward flow at the outside of the wake will cause the aircraft to bank away from the wake. A rapid approach from the side may result in the aircraft passing through the wake (See Figures 2.4-6 and 2.4-7).

Figure 2.4-6
Aircraft reaction to
wake turbulence
encounter,
approach from the
side (rear view
depiction)

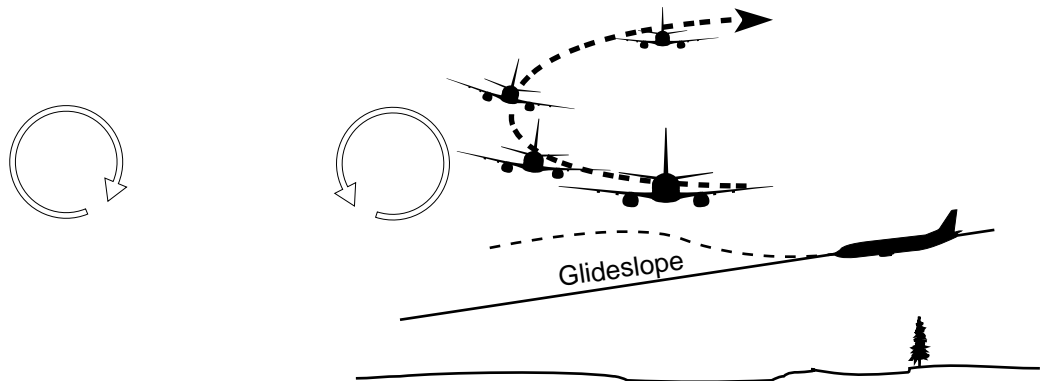
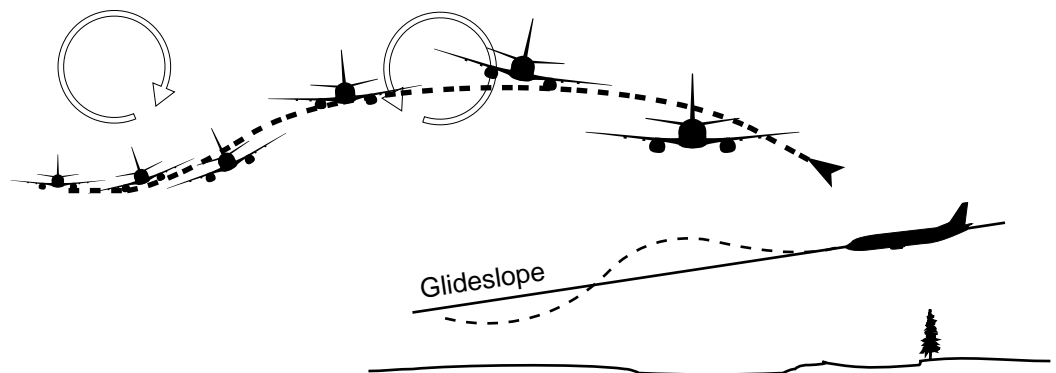


Figure 2.4-7
Aircraft reaction to
wake turbulence
encounter, rapid
approach from the
side (rear view
depiction)



When approached from below, the downward flow through the wake pushes the aircraft down and away from the wake. If approached at a rapid enough rate, the aircraft will pass through the wake (See Figures 2.4-8 and 2.4-9).

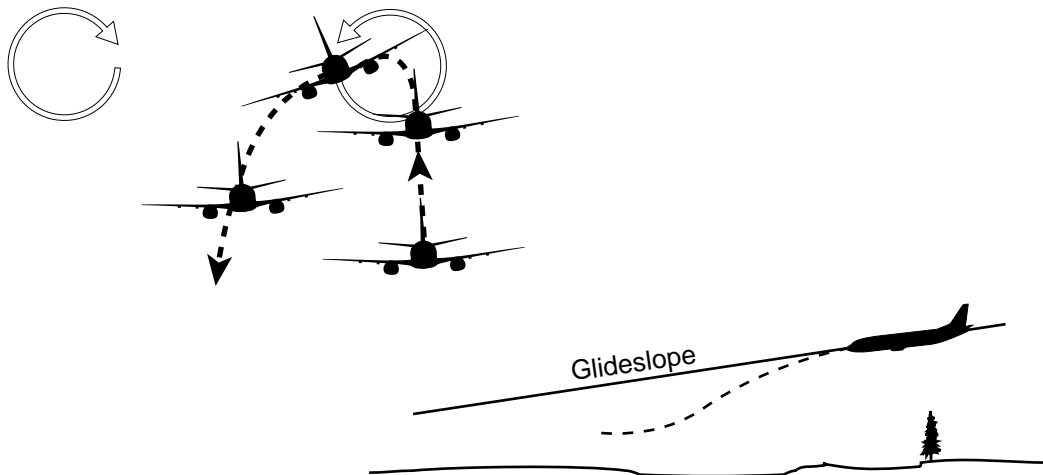


Figure 2.4-8
Aircraft reaction to
wake-turbulence
encounter, approach
from below right
(rear view depiction)

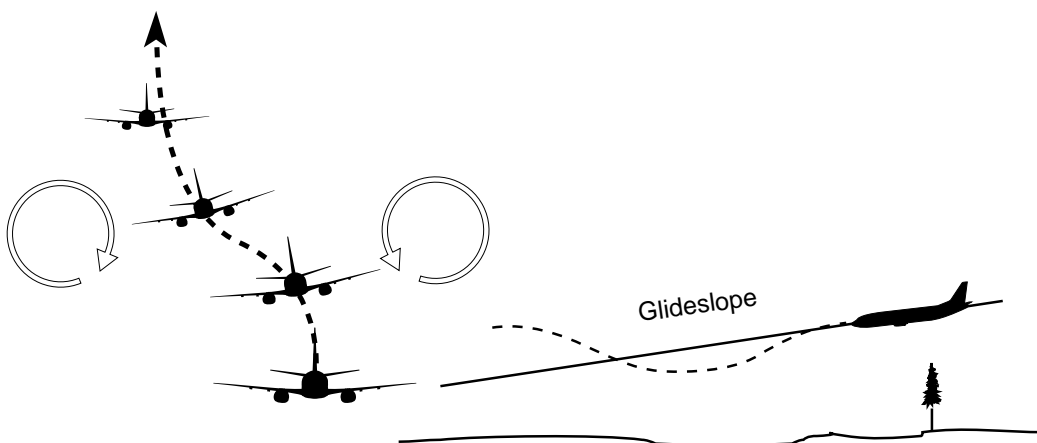


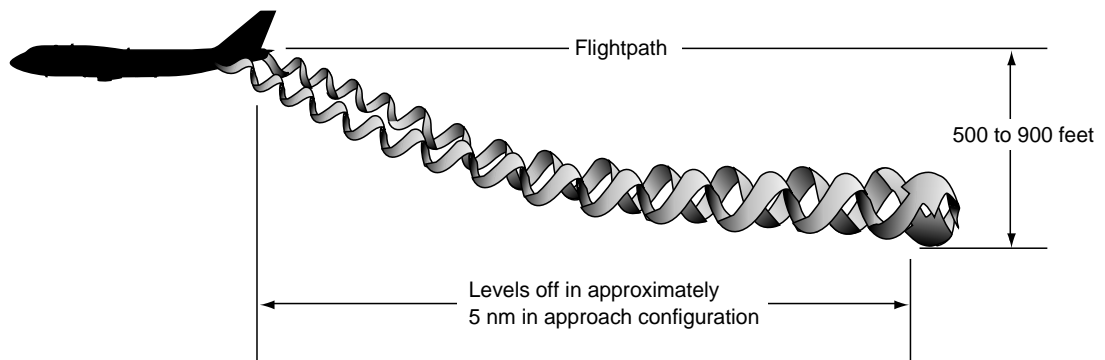
Figure 2.4-9
Aircraft reaction to
wake-turbulence
encounter, rapid
approach from
below (rear view
depiction)

2.4.4 Vertical Motion of the Wake

The wake of an aircraft has behavioral characteristics which can help the pilot visualize the wake location and thereby take avoidance precautions. The initial descent rate of the wake is adequately described by classical theory; the descent rate is determined by the weight, flight speed and wingspan of the generating aircraft. Generally, vortices descend at the initial rate of about 300 to 500 feet per

minute for about 30 seconds. The descent rate decreases and eventually approaches zero at between 500 and 900 feet below the flightpath. Flying at or above the flightpath provides the best method for avoidance. Maintaining a vertical separation of at least 1000 feet when crossing below the preceding aircraft may be considered safe. This vertical motion is illustrated in Figure 2.4-10.

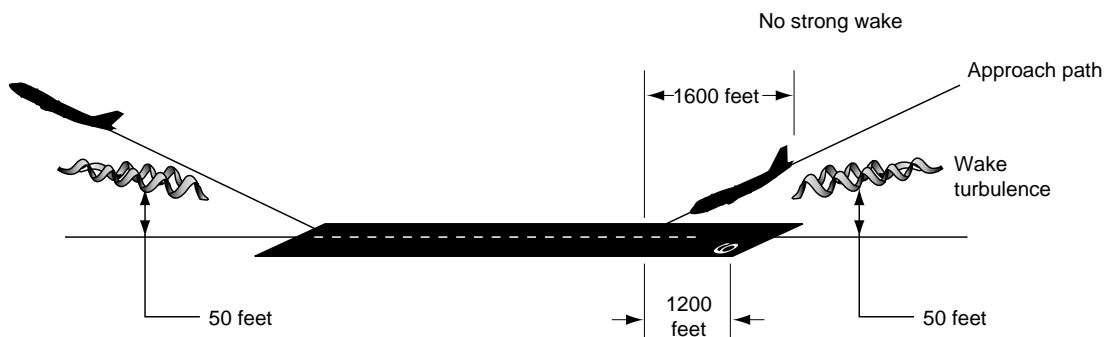
Figure 2.4-10
Vertical motion out
of ground effect



On approach and takeoff the wake descends below the flightpath until it enters ground effect whereupon the vortices slow their downward descent and move laterally as shown below. Typically, the wake's descent will be arrested within approximately 1/2 wingspan (50-100 feet for the B-747) of the ground. Be-

low this height the wake does not completely form into concentrated vortices and the turbulence in the wake is weakened. Thus, the turbulence level is reduced, but may still be a factor to aircraft in the touchdown area. This is illustrated in Figure 2.4-11.

Figure 2.4-11
Vertical motion in
ground effect



2.4.5 Horizontal Motion of the Wake

The horizontal motion of vortices is dictated by the ambient wind and the proximity of the vortices to the ground.

At altitude, the wake's horizontal motion is determined by the velocity of the wind. On approach and takeoff, the wake descends below the flightpath until it enters ground effect whereupon the vortices decrease their downward descent and move laterally. With no

crosswind, the two vortices move apart to clear the flightpath. Crosswinds of 1 to 5 knots can cause one vortex to remain near the flightpath. Crosswinds greater than 5 knots cause the vortices to move quickly across the flightpath and to break up. This is illustrated in Figure 2.4-12 below.

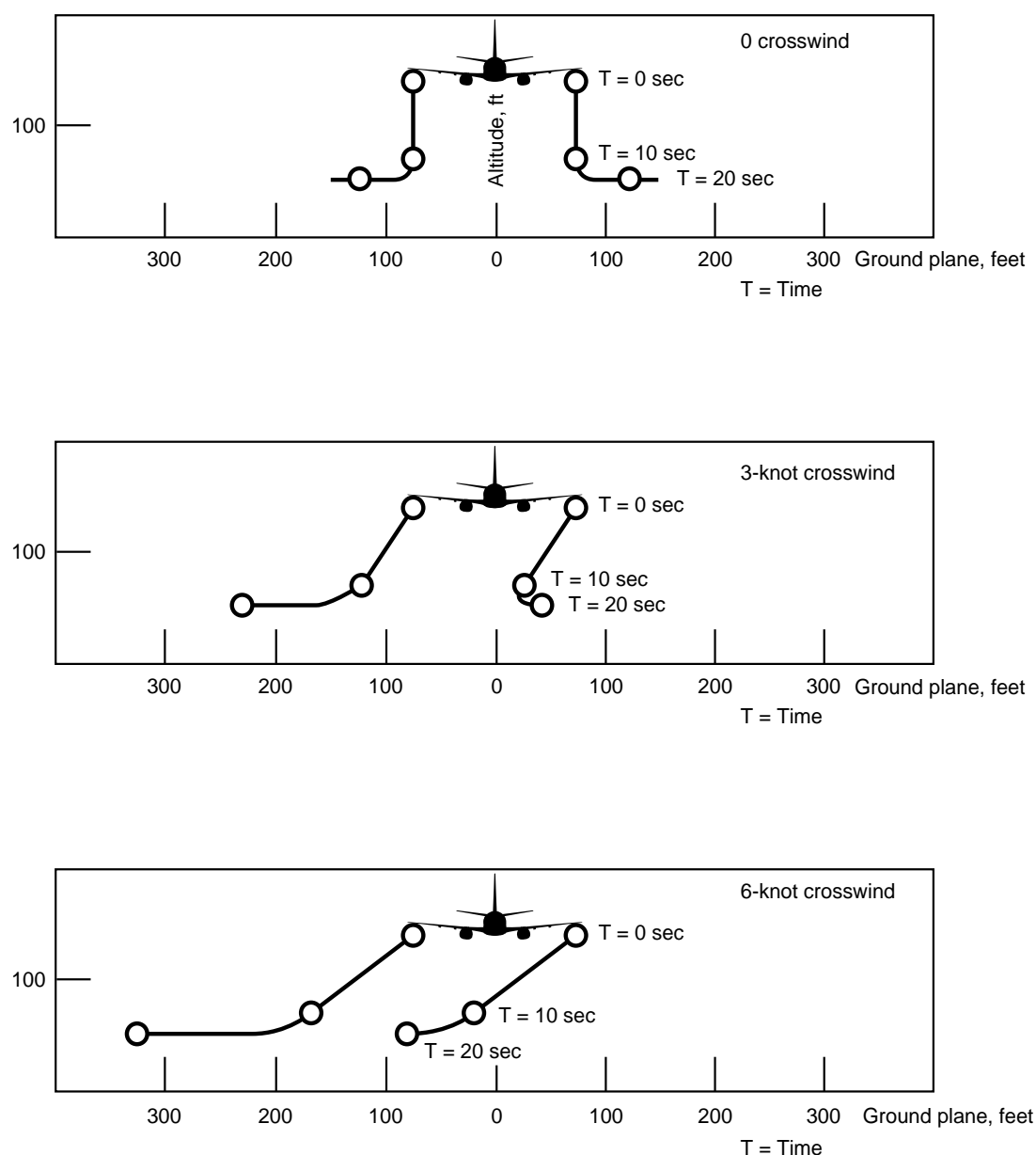


Figure 2.4-12
Horizontal motion

Vortices have been found to move laterally as much as 1500 feet under certain conditions, but with seemingly weak strengths at the larger lateral distances. Additionally, under some crosswind conditions, vortices have been observed to “bounce” (i.e., descend toward the ground and then later begin to rise up somewhat).

2.4.6 Decay Process

The decay process of the wake is complex and is strongly influenced by the atmospheric conditions. The decay process is driven by the following factors:

Atmospheric Turbulence. Atmospheric turbulence plays a significant role in the decay of the vortex. Atmospheric turbulence imparts viscous forces on the wake. These forces extract energy from the vortex, thus reducing its strength. The heavier the turbulence, the quicker the wake decays.

Viscous Interactions. The viscosity of the atmosphere slowly extracts energy from the vortex, thus reducing its strength.

Buoyancy. An upward force acts on the vortex as a result of the density inside the vortex system being lower than the density outside the vortex. This force also slowly extracts energy from the vortex; thus, reducing its strength.

Vortex Instability. A small amount of turbulence in the atmosphere can create an instability in the vortex pair that causes the vortices to link. When the vortices link, the strength of the pair decays rapidly.

2.4.7 Gaps in Our Knowledge

The initial behavior of the wake is well described by theory. However, the long-term behavior is strongly dependent on meteorological conditions. Work continues to fully understand the effects of meteorological conditions on the decay process.

2.5 Future Wake-Turbulence Detection Technology

There are many sensors/systems that have had or may have application in forecasting or detecting wake turbulence. These range in complexity from simple sensors, such as propeller anemometers, to complex systems, such as the FAA's Integrated Weather Sensing System (ITWSS). There is a general consensus that it would be desirable to use sensors/systems which already exist (such as the Low Level Windshear Alert System). However, there is currently nothing in operational use which meets all of the requirements for wake-turbulence sensing. There is not even complete agreement on what the requirements for wake-turbulence sensing should be.

Wake-turbulence sensor research is currently being conducted in the United Kingdom, France, Canada, Germany, and the United States. The U.S. research is the most extensive and includes research in most, if not all, of the areas of interest to other countries.

The primary areas of research are Radar, Lidar (Laser Radar), Sodar (acoustic Radar), Infrared sensors, and combinations of these technologies. A high-power radar has demonstrated the capability of detecting and tracking wakes, but not at the much lower power level which might be practical in a terminal area. Radar is not able to resolve whether a wake is hazardous or not as there is even some uncertainty over the source of the signal return. Radar research is continuing because it has a number of advantages as an operational sensor, even though technical results have not been as promising as for other sensors.

Laser systems have a long, successful history as research instruments for wake-turbulence measurements. They can detect, track, and measure wake strength. Research is continuing to improve their range and all weather capability. Because of their complexity, the primary challenge is to develop a safe, stand-alone system for operational use. Research systems have been used in several countries to develop a wake-turbulence database.

Acoustic systems have also proven successful in wake-turbulence research. Older systems required several sensors to track wake turbulence but new systems are being developed which can detect, track, and measure strength with a single sensor. Acoustic systems have provided most of the airport wake-turbulence strength measurements in the U.S. database. These systems are simpler and cheaper than Lasers but are limited in range (1000 feet or less).

Infrared sensor research for wind shear prompted tests of an infrared sensor for wake turbulence. These tests showed that there was an infrared signature associated with the passage of an aircraft. However, it is not clear if the signature is due to the temperature profile in the atmosphere or some characteristic of wake turbulence. This situation is so unclear that presently, infrared sensors are not considered promising.

In addition to the major sensor technologies, there is a continuous stream of ideas for new sensors based on new technologies or combinations of old technologies. During 1995 and 1996, the FAA/NASA Wake Vortex Program will evaluate vortex technology and select the most promising technology with the goal of developing and demonstrating an operational system by the year 2000.

2.6 Air Traffic Control Responsibilities for Maintaining Aircraft Separation*

Air traffic controllers play a large role in assuring that aircraft avoid wake turbulence since pilots are unable to visually apply avoidance procedures during IMC. Controllers, while providing radar vector service, are responsible for applying the wake-turbulence longitudinal separation distances between IFR aircraft and wake-turbulence advisories to VFR aircraft.

2.6.1 Wake-Turbulence Cautionary Advisories

Air traffic controllers are responsible for providing cautionary wake-turbulence information to assist pilots prior to their assuming visual responsibility for avoidance. Controllers must issue wake-turbulence cautionary advisories and the position, altitude if known, and direction of flight of heavy jets or B-757s to:

- a. VFR aircraft not being radar vectored, but which are behind heavy jets or B-757s.
- b. VFR arriving aircraft that have previously been radar vectored and the vectoring has been discontinued.
- c. IFR aircraft that accept a visual approach or visual separation.

Air traffic controllers should also issue cautionary information to any aircraft if, in their opinion, wake turbulence may have an adverse effect on it. When traffic is known to be a heavy aircraft, the word "heavy" should be included in the description.

*Information provided in Section 2.6 is compatible with FAA air traffic directives.

2.6.2 Radar/Approach Controllers

Within the terminal area, IFR aircraft are separated by 3 miles when less than 40 miles from the terminal antenna. A 2.5 nautical mile separation is authorized between certain aircraft which is established on the final approach course within 10 nautical miles of the landing runway when:

- a. The leading aircraft's Weight Class is the same or less than the following aircraft;
- b. Heavy aircraft and the B-757 are permitted to participate in the separation reduction as the following aircraft only;
- c. An average runway occupancy time of 50 seconds or less is documented;
- d. Bright Radar Indicator Tower Equipment displays are operational and used for quick glance references;
- e. Turnoff points are visible from the control tower.

Wake-turbulence procedures specify increased separation minima required for certain classes of aircraft because of the possible effect of wake turbulence. Refer to Appendix 4-F for FAA, United Kingdom and ICAO IFR radar controlled wake-turbulence separation criteria.

2.6.3 Tower Controllers

Tower controllers are responsible for runway separation for aircraft arriving or departing the airport. Tower controllers do not provide visual wake-turbulence separation to arrival aircraft; that is the pilot's responsibility. Tower controllers do provide wake-turbulence separation for departing aircraft by applying time intervals. Pilots may request a waiver to the wake-turbulence departure separation and the tower controller will then issue a "caution wake turbulence" advisory and clear the aircraft for takeoff provided no other traffic conflict exists.

2.6.3.1 Wake-Turbulence Separation for Departing Aircraft

Air traffic controllers are responsible for applying appropriate wake-turbulence separation criteria for departing aircraft. They will inform the pilot when it is necessary to hold an aircraft to provide the required wake-turbulence separation. The proper communication phraseology is "hold for wake turbulence." Pilots may request a waiver to deviate from the criteria. A pilot request for takeoff does not initiate a waiver request unless it specifically includes a request to deviate from the required wake-turbulence interval.

2.6.3.2 Wake-Turbulence Departure Separation Criteria

Separation criteria (listed by aircraft wake-turbulence weight categories and runway situation) are as follows:

- Same or parallel runways separated less than 2500 feet:
 - Small/large/heavy behind heavy - 2 minutes (same direction).
 - Small/large/heavy behind heavy - 3 minutes (opposite direction or intersection departure).

- Same runway:
 - Small behind large - 3 minutes (opposite direction or intersection departure).

Note: Aircraft conducting touch-and-go and stop-and-go operations are considered to be departing from an intersection.

- Intersecting runways:
 - Small/large/heavy behind heavy - 2 minutes (projected flightpaths cross or departure will fly through airborne path of arrival).

2.6.4 Visual Separation

Aircraft may be separated by visual means when other approved separation is assured before and after the application of visual separation. To ensure that other separation will exist, air traffic controllers should consider aircraft performance, wake turbulence, closure rate, routes of flight and known weather conditions. Reported weather conditions must allow the aircraft to remain within sight until other separation exists. Controllers should not apply visual separation between successive departures when departure routes and/or aircraft performance preclude maintaining separation.

2.6.4.1 Visual Separation-Terminal Area

Visual separation may be applied between aircraft under the control of the same facility within the terminal area provided:

- a. communication is maintained with at least one of the aircraft, involved or the capability to communicate is immediately available; and the aircraft are visually observed by the tower controller and visual separation is maintained between the aircraft by the tower controller.
- b. a pilot sees the other aircraft and is instructed to maintain visual separation from the aircraft as follows:
 - (1) The pilot is informed by the ATC of the other aircraft, including position, direction and, unless it is obvious, the other aircraft's intention.
 - (2) Acknowledgment is obtained from the pilot that the other aircraft is in sight.
 - (3) The pilot is instructed to maintain visual separation from the other aircraft.
 - (4) The pilot is advised if the radar targets appear likely to converge.
 - (5) If the aircraft are converging, the other aircraft is informed of the traffic and that visual separation is being applied.

The tower controller shall not provide visual separation between aircraft when wake-turbulence separation is required or when the lead aircraft is a B-757.

2.6.4.2 Visual Separation - En Route

Air traffic controllers may use visual separation in lieu of radar separation in conjunction with visual approach procedures. Refer to Section 2.6.4 for those procedures.

2.6.4.3 Visual Separation - Nonapproach Control Towers

Nonapproach control tower controllers may be authorized to provide visual separation between aircraft within surface areas or designated areas provided other separation is assured before and after the application of visual separation. This may be applied by the nonapproach control tower providing the separation or by a pilot visually observing another aircraft and being instructed to maintain visual separation with that aircraft.

2.7 Pilot Responsibilities for Maintaining Wake-Turbulence Separation

Pilots and air traffic control share the responsibility for assuring that aircraft avoid wake turbulence.

2.7.1 Who Does What and When

There is clear delineation of who and when responsibility is assumed for avoiding wake turbulence. The pilot is responsible for avoiding wake turbulence when:

- a. flying in VFR and not being vectored by ATC.
- b. maintaining visual separation.
- c. cleared for a visual approach.

Air traffic control (ATC) assumes wake-turbulence responsibility while providing the pilot instrument flight rules (IFR) control in instrument meteorological weather conditions and when vectoring VFR aircraft. [A discussion of ATC procedures is included in the ATC responsibility Section, 2.6.] A discussion of several situations will help to clarify a pilot's responsibility.

When the pilot is being radar controlled by ATC, the aircraft will be spaced, for wake turbulence, behind a preceding aircraft at a distance determined by the weights of the two aircraft. Based on the known movements of wake turbulence, this separation has been successful in preventing wake-turbulence encounters. The minimum separation is designed not only to allow time for the wake turbulence to begin to dissipate, but also to allow time for it to descend below the following aircraft's flightpath. Longitudinal separation is but one element of avoidance. If VFR weather conditions exist when ATC is providing radar control, the pilot is not relieved of the responsibility for assuring the flightpath will avoid an encounter with wake turbulence. If instrument meteorological conditions (IMC) exist, only the ATC established separation distances are available to prevent wake-turbulence encounters, since the pilot is unable to visually apply avoidance procedures.

When it is operationally beneficial, ATC may authorize the pilot to conduct a visual approach to an airport or to follow another aircraft in VFR weather. The pilot must have the airport or an identified preceding aircraft in sight before the clearance is issued. If the pilot has the airport in sight but cannot see the aircraft he or she is following, ATC may still clear the aircraft for a visual approach; however, ATC retains both normal separation and wake-turbulence separation responsibility. When the pilot is able to visually follow a preceding aircraft, and accepts the visual approach clearance, this transfers responsibility for avoiding wake turbulence to the pilot. To summarize this point, the pilot accepts wake-turbulence avoidance responsibility when:

- a. ATC instructions include traffic information.
- b. Instructions to follow an aircraft are given and the pilot is able to comply.
- c. The pilot accepts the visual approach clearance.

ATC is also responsible for assuring proper wake-turbulence separation before issuing clearance for takeoff by applying time and distance intervals. Pilots, after considering possible wake-turbulence effects, may specifically request a waiver to the interval. Controllers may acknowledge this request as acceptance of responsibility for wake-turbulence separation. If traffic permits, takeoff clearance will be issued. A wake-turbulence cautionary advisory will be given.

During cruise flight in VFR weather, altitude separations could be as little as 500 feet between IFR and VFR aircraft. In this situation the same principle applies: pilots must use proper avoidance procedures.

2.7.2 Communications

To aid other pilots and ATC within FAA controlled airspace, pilots of heavy aircraft should always use the word "Heavy" in their radio communications. Radio communications are usually country specific, therefore pilots should check appropriate regulations regarding wake turbulence prior to operations outside FAA controlled airspace.

ATC is required to provide a "CAUTION WAKE TURBULENCE" advisory when VFR aircraft are not being radar vectored and are behind heavy jets or B-757s and to IFR aircraft that accept visual separation or a visual approach. ATC controllers may also issue a wake-turbulence caution when, in their opinion, wake turbulence may have an adverse effect on an aircraft following another aircraft. Because wake-turbulence movement is variable, the controller is not responsible for anticipating its existence or effect. Although not mandatory during ground operations, controllers may use the words jet blast, propwash, or rotorwash, in lieu of wake turbulence, when issuing a caution advisory.

2.8 Wake Turbulence Recommended Visual Avoidance Procedures

It would be easy to avoid wake turbulence if it could be seen. Although under certain atmospheric or artificially generated conditions it is possible to see wake turbulence, this is not the normal situation. Therefore, pilots must rely on their knowledge of the behavior or characteristics of wake turbulence to visualize the wake location so that they may implement avoidance procedures. These procedures have been developed for various situations. It is important to note that the procedures require pilots to adjust their operations and flightpath to preclude wake encounters. Aircraft performance should be considered during the decision process of applying the procedures. Generally, the procedures were developed to assist pilots in

avoiding the area below and behind the generating aircraft. A go around may be the appropriate solution in some situations.

2.8.1 Specific Procedures

2.8.1.1 Landing Behind a Larger Aircraft - Same Runway (Figure 2.8-1)

- Stay at or above the larger aircraft's final approach flightpath.
- Note its touchdown point.
- Land beyond the touchdown point, runway length permitting.
- If unable to land safely beyond the touchdown point, go around.

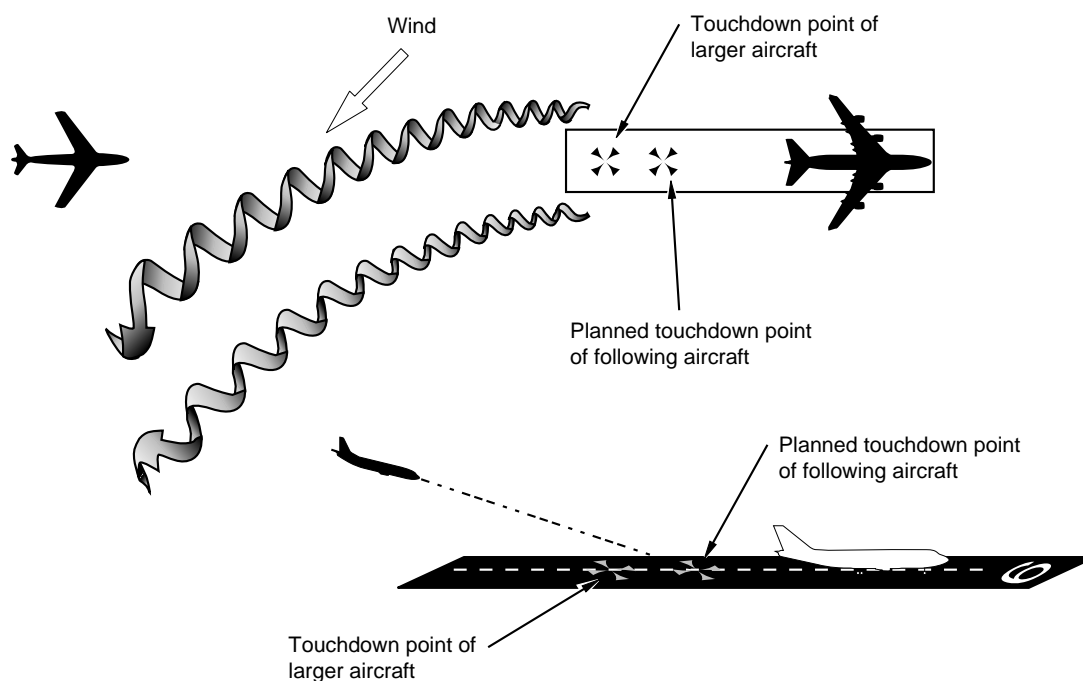
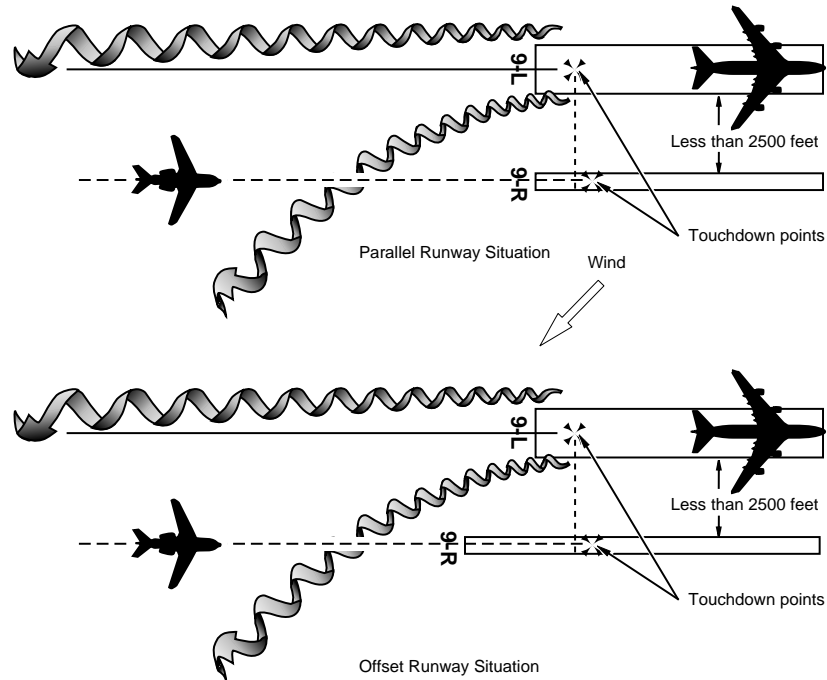


Figure 2.8-1
Landing behind a
larger aircraft
- same runway

2.8.1.2 Landing Behind a Larger Aircraft - Parallel Runway Closer Than 2500 Feet (Figure 2.8-2)

- Consider possible wake-turbulence drift to your runway.
- Stay at or above the larger aircraft's final approach flightpath.
- Note its touchdown point.

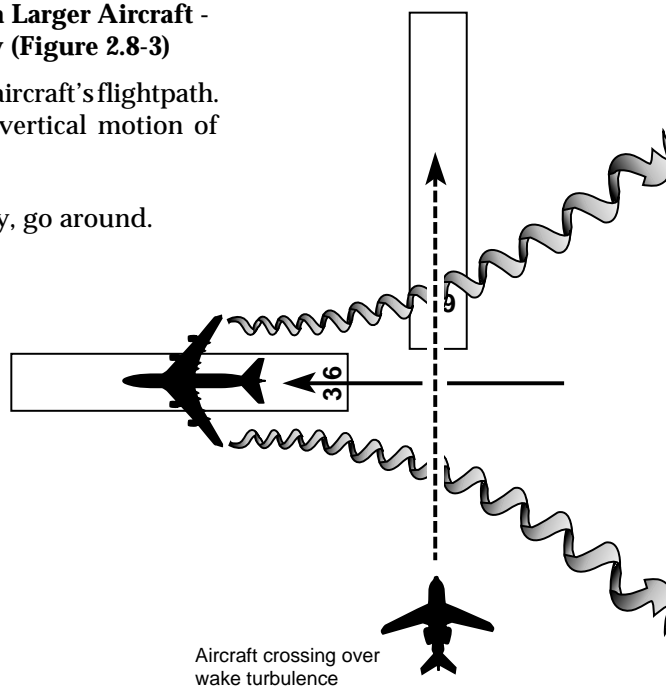
Figure 2.8-2
Landing behind a
larger aircraft -
parallel runway
closer than 2500
feet



2.8.1.3 Landing Behind a Larger Aircraft - Crossing Runway (Figure 2.8-3)

- Cross above the larger aircraft's flightpath. Consider lateral and vertical motion of wake turbulence.
- If unable to land safely, go around.

Figure 2.8-3
Landing behind a
departing larger
aircraft - crossing
runway



2.8.1.4 Landing Behind a Departing Larger Aircraft - Same Runway (Figure 2.8-4)

- Note the larger aircraft's rotation point.
- Land before the rotation point, or go around.

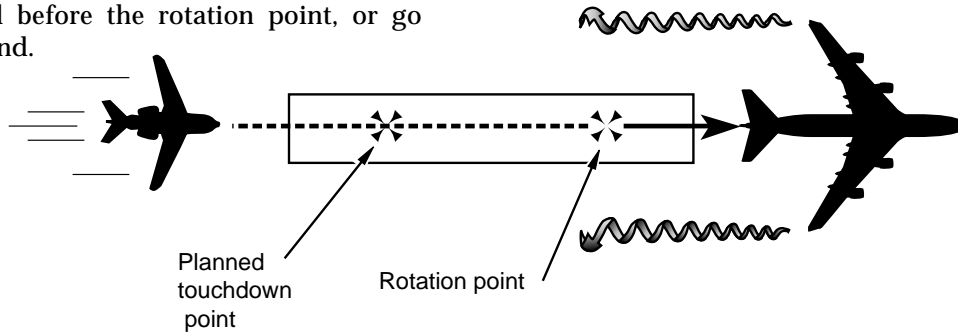


Figure 2.8-4
Landing behind a
departing larger
aircraft - same runway

2.8.1.5 Landing Behind a Departing Larger Aircraft - Crossing Runway (Figures 2.8-5,-6)

- Note the larger aircraft's rotation point. If past the intersection, continue the approach and land before the intersection.
- If larger aircraft rotates before the intersection, avoid flight below larger aircraft's flightpath. Abandon the approach unless a landing is assured well before reaching the intersection.

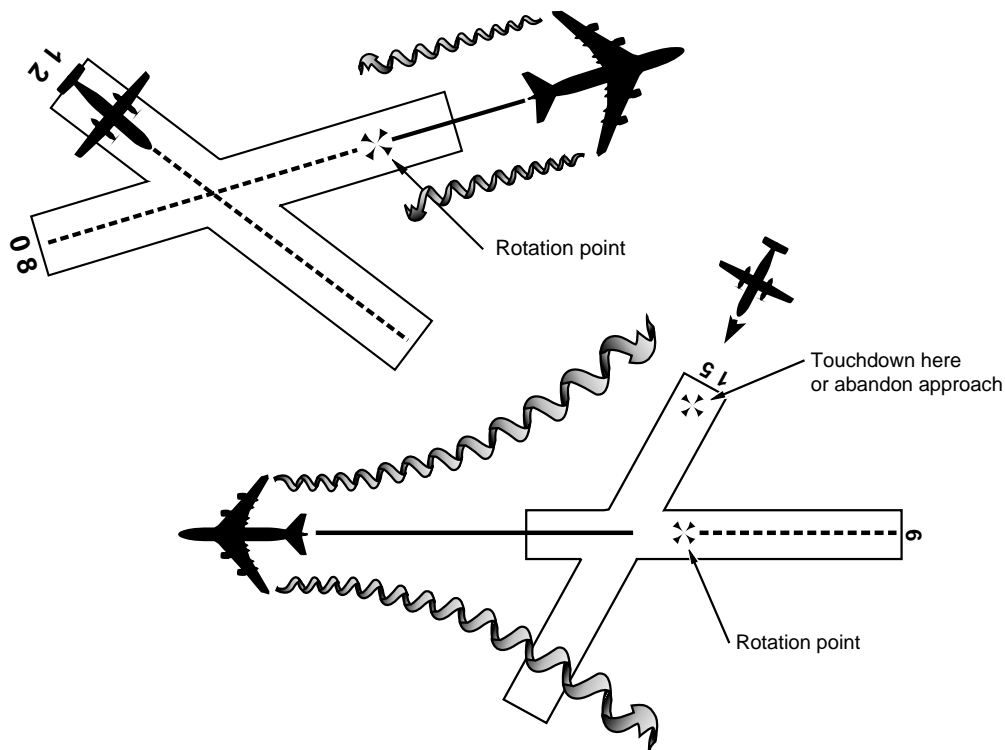


Figure 2.8-5
Landing behind a
departing larger
aircraft - crossing
runway

Figure 2.8-6
Landing behind a
departing larger
aircraft - crossing
runway

2.8.1.6 Departing Behind a Larger Aircraft (Figures 2.8-7,-8,-9)

- Note the larger aircraft's rotation point.
- Delay, do not begin take-off roll unless your rotation point will be prior to the larger aircraft's rotation point.
- Climb displaced upwind of larger aircraft.
- Continue climb above the larger aircraft's climb path until turning clear of its wake. **Caution:** This may not be possible because of the larger aircraft's performance.
- Avoid subsequent headings which will cross below and behind a larger aircraft.
- Be alert for any critical take-off situation which could lead to a wake-turbulence encounter.

Figure 2.8-7
Departing behind a
larger aircraft -
same runway

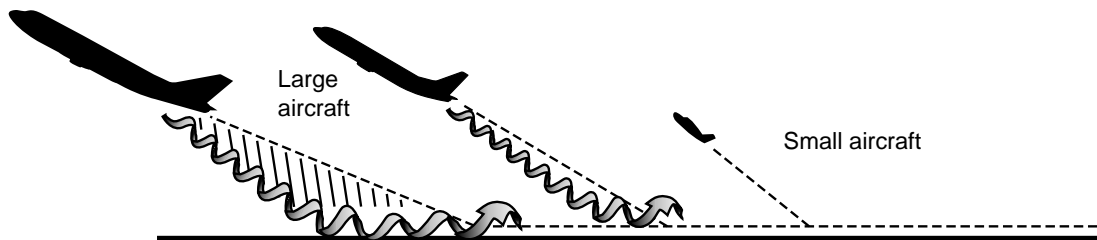


Figure 2.8-8
Departing behind a
larger aircraft -
crossing departure
courses

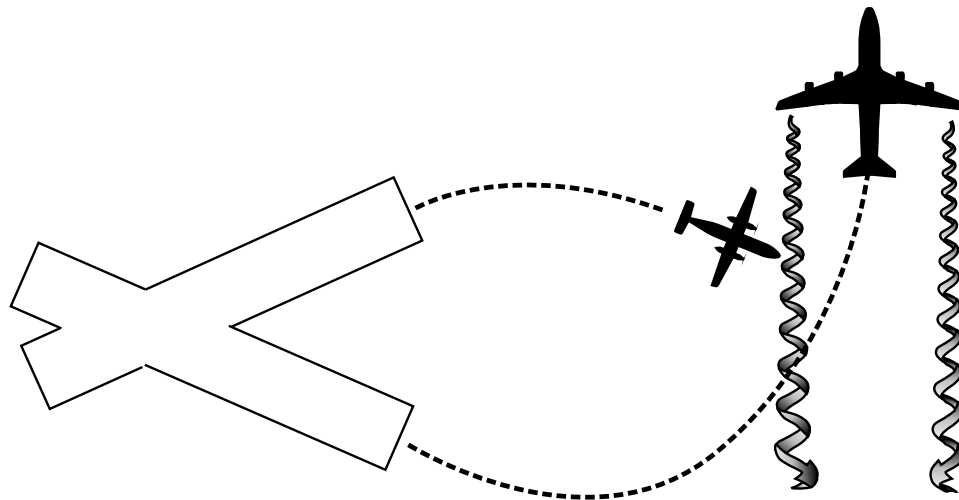
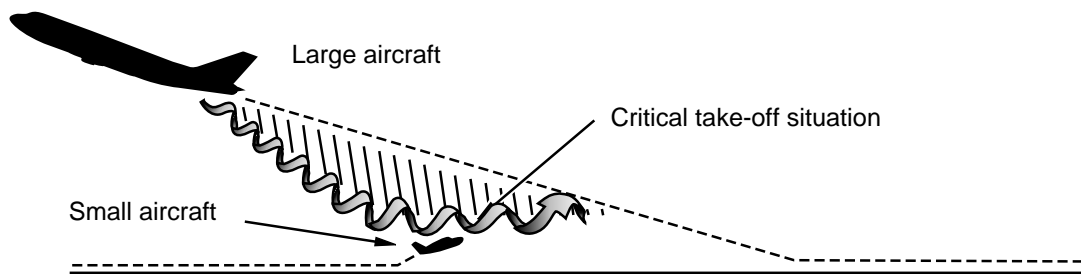
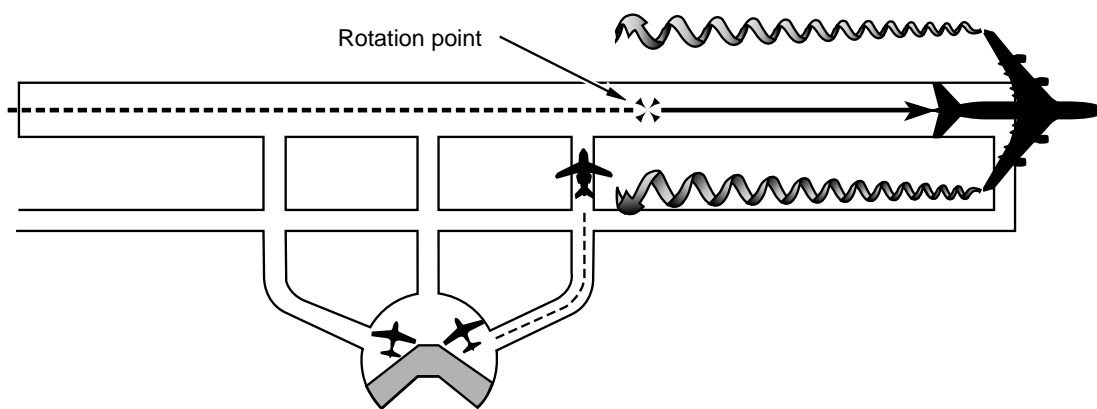


Figure 2.8-9
Departing behind a
larger aircraft -
opposite direction



2.8.1.7 Intersection Takeoffs - Same Runway (Figure 2.8-10)

- Be alert to adjacent larger aircraft operations, particularly upwind of your runway.
- If intersection take-off clearance is received, avoid headings which will cross below a larger aircraft's path.
- Ensure your rotation point is before larger aircraft's rotation point, or delay takeoff.

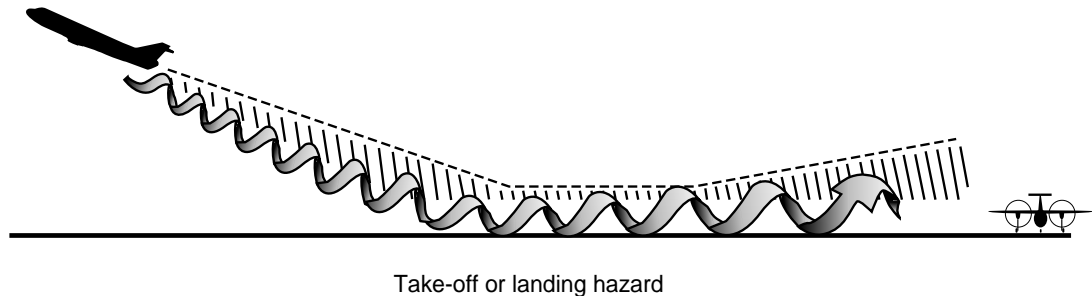


*Figure 2.8-10
Intersection takeoffs -
same runway*

2.8.1.8 Departing or Landing After a Heavy Aircraft Executing a Low Approach, Missed Approach or Touch-and-Go Landing (Figure 2.8-11)

- Ensure that an interval of at least two minutes has elapsed before your take off or landing.

*Figure 2.8-11
Departing or
landing after a
heavy aircraft
executing a low
approach, missed
approach or touch-
and-go landing*

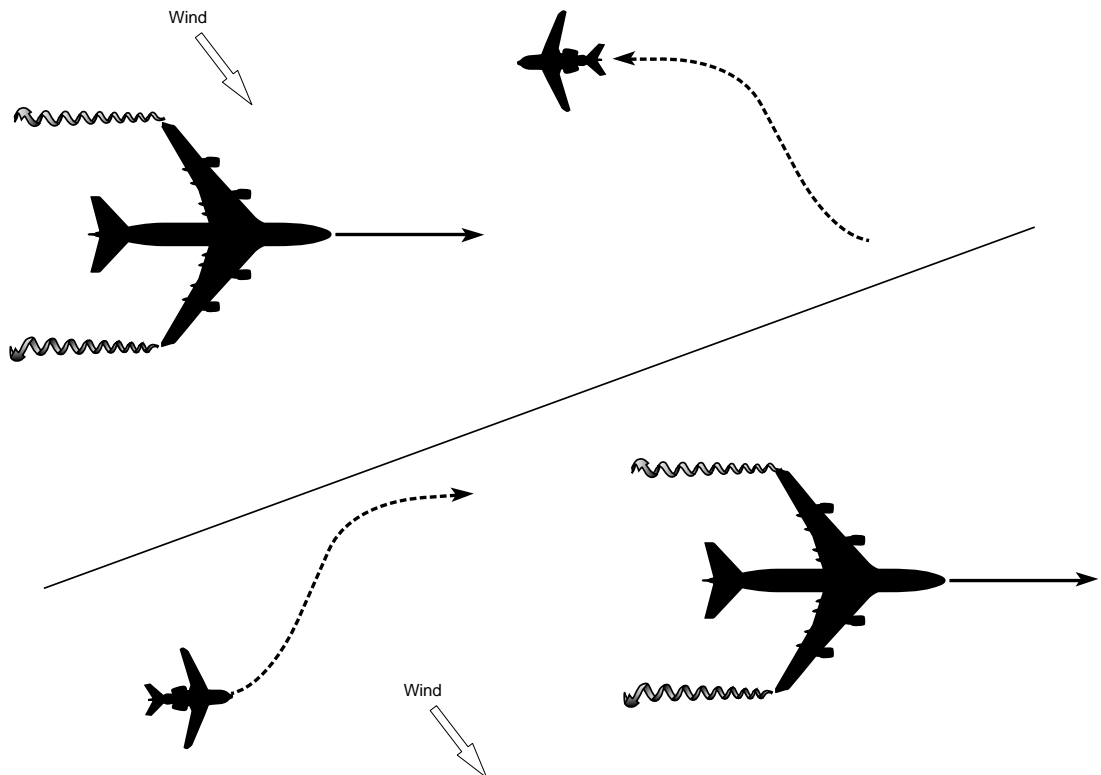


2.8.1.9 En Route Within 1000 Feet Altitude of a Large Aircraft's Altitude (Figure 2.8-12)

- Avoid flight below and behind a large aircraft's path.

- If a larger aircraft is observed above and on the same track (meeting or overtaking), adjust your position laterally, preferably upwind.

*Figure 2.8-12
En route VFR (1000
foot altitude plus
500 feet)*



2.8.2 Avoiding Helicopter Outwash Vortices

In a slow hover taxi or stationary hover near the surface, helicopter main rotor(s) generate downwash producing high velocity outwash vortices to a distance approximately three times the diameter of the rotor. When rotor downwash contacts the surface, the resulting outwash vortices have behavioral characteristics similar to wingtip vortices of fixed-wing aircraft. However, the vortex circulation is outward, upward, around and away from the main rotor(s) in all directions. Pilots of small aircraft should avoid operating within three rotor diameters of any helicopter that is in a slow-hover taxi or stationary hover (Figure 2.8-13).

In forward flight, departing or landing helicopters produce a pair of strong, high-speed trailing vortices similar to wingtip turbulence of larger fixed-wing aircraft (Figure 2.8-14). Pilots of small aircraft should use caution when operating behind or crossing behind landing and departing helicopters. Additionally, it is possible for the wake turbulence from a helicopter that hovers upwind of a runway to drift towards the runway.

In certain situations, ATC will use the phrase, “caution, wake turbulence.” Pilots must be aware that whether or not a warning has been given, they are expected to adjust their operations and flightpath as necessary to preclude serious wake encounters.

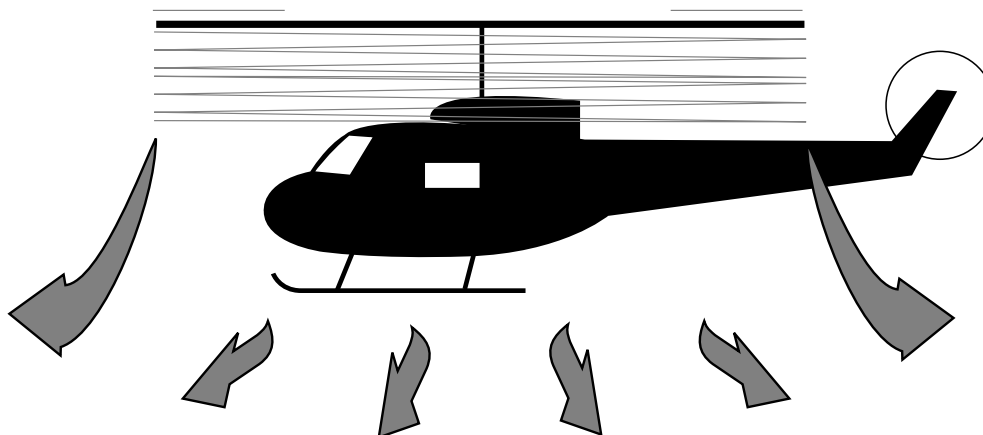


Figure 2.8-13
Helicopter hover-
produced
downwash

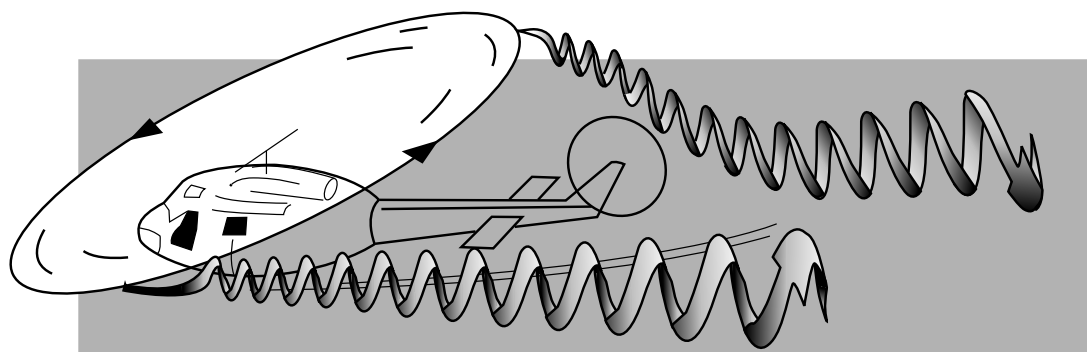


Figure 2.8-14
Helicopter forward-
flight-produced wake
turbulence

2.9 Pilot Difficulty in Visually Maintaining Separation

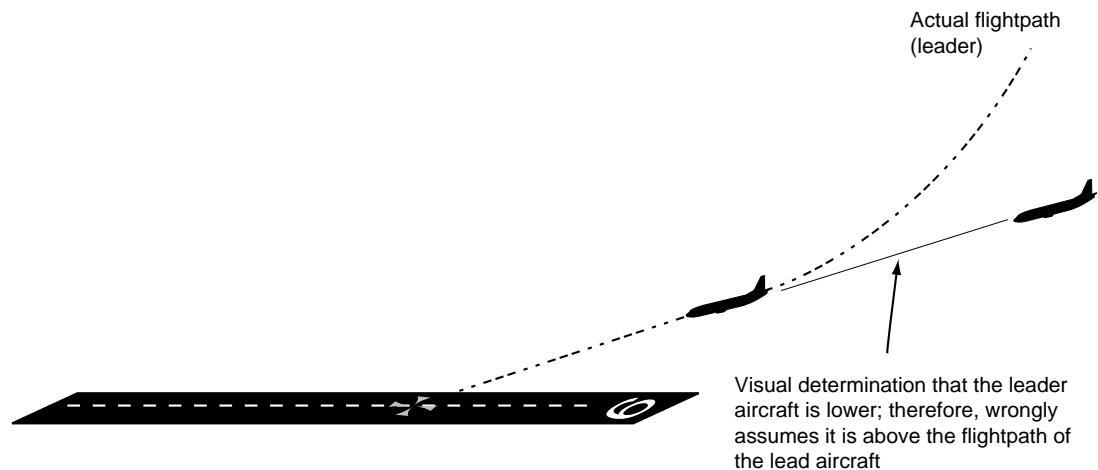
2.9.1 Flightpaths

A review of accidents and incidents involving wake turbulence reveals a recurring problem that pilots routinely must solve during arrival and landing. Traffic and airspace as well as other considerations require the establishment of flight patterns for sequencing aircraft for landing. These patterns are designed to accommodate arrivals from several directions, as well as approaches and landings under IFR and VFR weather conditions. Pilots may fly visual approaches when weather conditions permit and authorized by ATC at controlled airports. The pilot is then solely responsible for avoiding the wake turbulence when other

aircraft are present by staying at or above the flightpath of any aircraft they may follow. The task of maintaining a proper visual relationship with the lead aircraft becomes greater and more complicated when aircraft of different sizes and speeds, approaching from various altitudes and directions, are involved. These complexities increase the difficulty in maintaining the appropriate flightpath.

Even though the leader aircraft is currently below you, do not assume that the flightpath of the leader aircraft is below you. It is quite possible that the leader aircraft varied its descent rate, especially during the initial portion of its approach (Figure 2.9-1).

Figure 2.9-1
Steeper flightpath
by leader aircraft



2.9.1.1 Use of ILS Glideslope

When available to the pilot, the ILS glideslope can be a starting point for assistance in determining the flightpath of a leader aircraft; however, it is not foolproof. In fact, the leader aircraft may have intercepted and flown above the glideslope for wake-turbulence avoidance or other reasons.

2.9.1.2 Visual Illusions

Pilots can experience visual illusions for several reasons. Different aircraft sizes can make it difficult for pilots to determine distances or rates of closure with a leader aircraft. Additionally, the body attitudes of some aircraft significantly change as airspeed is reduced. The change in aircraft body attitude can give the illusion of a change in flightpath. Aircraft approaching from different directions and altitudes while turning to final approach is another situation where it is difficult for pilots to determine what the leader's flightpath was or will be when becoming aligned behind the leader.

2.9.1.3 Darkness/Reduced Visibility

Determining the leader aircraft's flightpath during darkness can be difficult for pilots. Depth perception is inhibited and pilots may have to rely only on the leader aircraft's lighting when ascertaining its flightpath. It is also difficult to determine flightpaths during reduced visibility caused by weather conditions.

2.9.2 Instrument to Visual Situation

Changing from an instrument approach to a visual approach and landing, when conditions permit, is routinely accomplished. The pilot's situational awareness up until the time of transition from IMC to VMC is usually limited to information received from radio communications. While ATC will issue information and cautionary instructions, the pilot must be prepared to react to the traffic situation and apply proper avoidance procedures.

2.10 Pilot Techniques for Visually Maintaining Separation

2.10.1 General

The wake-turbulence avoidance procedures discussed in Section 2.8 are effective when properly used. To properly apply avoidance procedures and techniques, it is important for pilots to know and understand the characteristics and movement of wake turbulence discussed in Section 2.4. Normally, it is not possible for pilots to know the precise location of wake turbulence. Pilots must therefore avoid the area below and behind larger aircraft flightpaths, especially at low altitude where even a momentary wake encounter could be hazardous. While this is not always easy to do, there are some techniques that may be used. Pilots should always consider their aircraft performance when avoiding wake turbulence since several procedures and techniques may require some adjustments to routine operations. Notification of ATC may also be necessary.

For pilots to be able to avoid wake turbulence by staying on or above the flightpath of the leader aircraft, trailing pilots must make some assumptions on where the leader has flown since there is no available visual reference. The use of visual glideslope indicators such as VASI or PAPI or instrument precision approach aids, when possible, will assist in establishing and maintaining a normal approach flightpath* and runway centerline course. If external aids are not available and obstacles are not a factor, a descent rate of 300 feet per nautical mile traveled approximates a 3-degree flightpath. The aircraft should be stabilized on a flightpath not later than 500 feet AGL. Air traffic controllers and pilots must understand that accomplishing a steep descent may have serious ramifications for trailing aircraft with regard to wake turbulence.

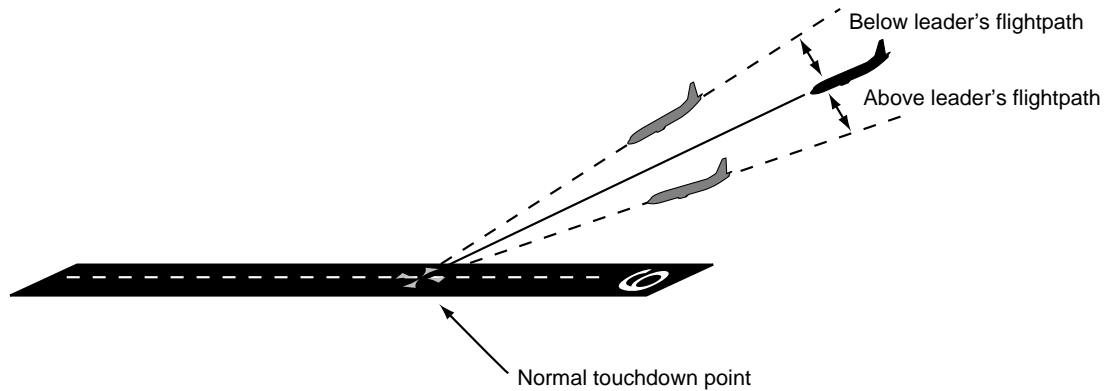
*Heavy wide-body aircraft pilots routinely fly the upper two rows of VASI lights.

2.10.2 Visual Cues for Estimating Leader's Flightpath

One way to determine the flightpath that the leader has flown is to extend an imaginary line from your position to the runway normal touchdown point (Figure 2.10-1A). If the leader aircraft is above this line, you are below

its flightpath. Conversely, if the leader aircraft is on or below the imaginary line, you are on or above its flightpath. This technique assumes the leader has flown a consistent flightpath and is using a normal runway touchdown point.

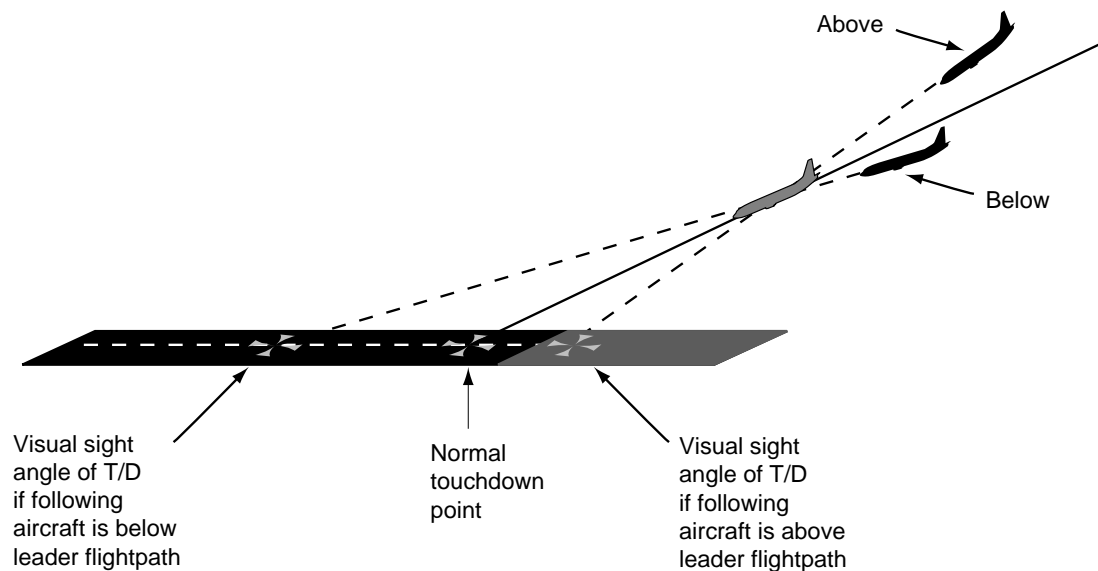
Figure 2.10-1A
Determining
flightpath of leader
using imaginary
line extension
method



While following an aircraft, extending an imaginary line from your aircraft through the leader to the runway should end at the normal runway touchdown point (Figure 2.10-1B). If it ends at a point down the runway, the

trailing aircraft is probably below the flightpath of the leader. If the imaginary line extension is prior to the touchdown point, e.g., in the overrun, the trailing aircraft is probably above the leader's flightpath.

Figure 2.10-1B
Determining if
follower is above or
below leader



2.10.3 Using ILS Glideslopes for Vertical Separation

When ILS approaches are being used, consideration may be made by the pilot of the trailing aircraft to fly at or above the ILS glideslope. This assumes the leader aircraft is positioned on the glideslope. Be alert! This assumption is not always valid. A nose high pitch attitude

of the leader aircraft should not be used as an indicator of glideslope position because pitch attitudes vary among aircraft types and manufacturers. Table 2.10-1 provides distance in feet for degrees in deviation from the glideslope and illustrates position relative to the glideslope.

Miles from touchdown (nm)	5	4	3	2	1
One-dot (1/4 degree) deviation	130'	104'	78'	52'	26'
Two-dot (1/2 degree) deviation	260'	208'	156'	104'	52'

Table 2.10-1
*Deviation from
standard 3-degree
glideslope*

Note: The relative distance from the glideslope becomes quite insignificant close to the runway.

2.10.4 Using ILS Localizer for Lateral Separation

During crosswind conditions, pilots may consider flying offset on the upwind side of the localizer centerline as a means of avoiding the leader's wake turbulence. This assumes the

leader is flying on the localizer course. Table 2.10-2 can be used to determine offset distance in feet for degrees in deviation from the localizer course.

Miles from touchdown (nm)	5	4	3	2	1
One-dot (1-1/4 degree) deviation	838'	706'	573'	441'	308'
Two-dot (2-1/2 degree) deviation	1677'	1412'	1147'	882'	617'

Table 2.10-2
Localizer deviation

2.10.5 Longitudinal Separation

Pilots may also establish longitudinal separation from a leader aircraft so as to allow time for the wake turbulence to move or dissipate. Judging in-flight distances is not always easy to do because different aircraft sizes can be visually deceiving to the pilot.

2.10.5.1 Air Traffic Control Assist

Air traffic controllers are able to provide separation distance information to pilots when workload permits and they have radar displays in the control tower. They can provide airspeed differential between aircraft and may advise pilots following another aircraft when they are overtaking the preceding aircraft.

2.10.5.2 On-board Radar

Aircraft equipped with radar may have the capability to determine separation distances from other aircraft. Caution: Be careful not to focus attention on the radar at the expense of outside visual scans.

2.10.5.3 Time and Distance Methods

A technique available for the pilot of the following aircraft is to start timing the leader aircraft when it or its shadow passes a recognizable geographical reference point. Radio call points can also be used for timing references. Determine the amount of time it takes for the following aircraft to pass over the same point. Convert that time into distance. For example, if it took three minutes and the following aircraft's ground speed was 120 knots (two miles per minute), then the distance between the two aircraft is six miles.

Most heavy and large aircraft produce some smoke from the tires during touchdown on landing. Pilots of trailing aircraft, upon observing the smoke, can estimate their own position from touchdown as well as determining a point to land beyond. Knowing the distance from the runway to an instrument final approach fix or an available landmark can be helpful in determining relative distances.

2.10.6 Establishing Longitudinal Separation

There are several ways to increase separation distances while following an aircraft on final approach. Several factors should be considered before implementing these techniques: aircraft performance, in-flight visibility, other traffic in the pattern as well as those that are taking off or preparing to take off, notification of ATC, etc.

Airspeed reduction is an obvious choice of most pilots, but usually is limited to small changes because of aircraft performance or ATC restrictions. Pilots must not reduce airspeed below the aircraft's minimum safe operating speed. Also, recovery from an inadvertent wake-turbulence encounter is more difficult at slower airspeeds. For planning purposes, most transport category aircraft final approach speeds are between 120 knots to 150 knots.

Flying "S" turns is another way to gain separation.

A 360-degree turn will greatly increase the distance from the leader, but the impact on other aircraft may preclude its use.

The decision to abort the approach or landing and go around is always an alternative for avoiding wake turbulence.

2.10.7 Radio Communications

Listening to all radio communications (not just those directed to you) can be helpful in providing information that can improve wake-turbulence situational awareness. Prior to entering a visual traffic pattern or initiating an instrument approach, radio communications between ATC and other aircraft can alert pilots to where they may fit in the landing sequence or what type aircraft they may follow. Takeoff and landing clearances for other aircraft provide pilots information that can be useful for spacing considerations as well as anticipating the location of generated wake turbulence. Do not overlook any information that can aid planning and flying an approach, landing or go-around.

2.10.8 Estimating Movement of Wake Turbulence

Basic surface wind indications can aid pilots with estimating the movement of wake turbulence. Blowing dust, smoke or wakes on lakes and ponds provide indications that may be used in determining wind direction which may be applied to wake-turbulence movement. Use any on-board avionics equipment i.e., inertial reference, Doppler radar, global positioning system, etc. to determine wind direction. Aircraft drift angles will also give the pilot an indication of wind direction.

2.11 Pilot Responses Upon Encountering Wake Turbulence

An encounter with wake turbulence usually results in induced rolling or pitch moments; however, in rare instances an encounter could cause structural damage to the aircraft. In more than one instance, pilots have described an encounter to be like “hitting a wall”. The dynamic forces of the vortex can exceed the roll or pitch capability of the aircraft to overcome these forces. During test programs, the wake was approached from all directions to evaluate the effect of encounter direction on response. One item that was common to all encounters, without a concerted effort by the pilot the aircraft would be expelled from the wake. Refer to Section 2.4, Figures 2.4-4 through 2.4-9, for the effects on an aircraft when encountering wake turbulence from several directions. While this information provides a better understanding of wake turbulence, its usefulness is limited since wake-turbulence encounters are inadvertent and pilots will not be aware of their entry location.

Counter control is usually effective and induced roll is 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 wingspan (relative to the generating aircraft) to counter the imposed roll induced by the vortex flow. Pilots of short span aircraft, even of the high performance type, must be especially alert to wake-turbulence encounters.

It may be difficult or impossible for pilots to differentiate between wake turbulence and turbulence generated from another source. Apply appropriate corrective action if wake turbulence is encountered. A wake-turbulence encounter at low altitude is much more hazardous than an encounter at cruise altitude or early during the approach phase of flight.

2.12 Cooperative and Efficient Management of Capacity

The worldwide number of aircraft continues to increase each year for reasons that reach from the desire for greater recreational use to responding to commercial demand. As this number increases, so must the necessary support or infrastructure. The critical or limiting factor of this infrastructure continues to change. For example, in the early years of aviation, the small number of runways often limited where a pilot could land. As more runways were built, adverse weather became the critical element which was slowly overcome with the advent of better and better terminal approach aids and air traffic systems. We have evolved from few pilots to many pilots; from few air traffic controllers to many air traffic controllers. Most of the limiting factors have gradually been mitigated though improved technology. Currently, wake turbulence and the application of existing IFR separation and avoidance procedures are a limiting factor at many major airports. This situation, coupled with high air traffic density, creates an environment that requires pilots and air traffic controllers to cooperate to safely and efficiently conduct flight operations.

Air traffic controllers should understand that many times the pilot’s situational awareness is limited to information provided by ATC until the pilot enters visual meteorological conditions. This means that initially it may be difficult for pilots to visually detect whether they may be overtaking the leader aircraft or where they are, relative to the leader’s flightpath. Any pertinent information that can be given to the pilot during a radar controlled arrival, will help the pilot transition to a visual approach and landing.

Delaying a pilot's descent increases the cockpit workload and difficulty in accomplishing a normal approach for landing. A higher than normal approach can impact trailing aircraft. The leader aircraft may not be aware of trailing aircraft or of their position.

Pilots can assist ATC in several ways. One way is to understand that ATC is continually challenged in sequencing arrivals with departures, planning for different aircraft with different performance characteristics and applying wake-turbulence separation criteria. A pilot who initiates an unusual request or makes a change in his/her flight operations from what is normally expected by ATC, will probably increase an already high workload for most controllers at major airports. Early, precise and disciplined radio communications with ATC improves the flow of vital information.

Wake turbulence is one of many factors that pilots and air traffic controllers must overcome to fly safely. It takes cooperation among pilots and air traffic controllers and understanding of each other's requirements to safely avoid wake turbulence.

2.13 Air Traffic Considerations When Applying Separation

Air traffic control is responsible for the safe, orderly and expeditious flow of all aircraft in their area of responsibility. The primary considerations that affect the controller's ability to do this are:

- Type of approaches available (IFR or VFR)
- Mix of traffic (turbojet, propeller, helicopter)
- Traffic density
- Wake-turbulence separation
- Noise abatement procedures.

The terminal approach control can safely land

and depart more aircraft if the weather is VFR and visual approaches are being used. Typically, aircraft flying visual approaches will have approximately 1-1/2 miles between landing and arriving aircraft. Under IFR weather conditions, aircraft require a minimum of 2-1/2 miles inside the final approach fix and if wake-turbulence separation is required, the separation may be extended up to 4, 5, or 6 miles between aircraft. Traffic density is the major factor in the amount of aircraft that can be safely, orderly and expeditiously landed or departed. The busiest airports schedule aircraft takeoffs and landings based on weather conditions. At almost any busy airport, when the weather is IFR, there are extensive delays and even cancellations if the IFR weather persists for an extended period of time.

Visual conditions and visual separation allow air traffic to handle more aircraft in the system. When controllers clear pilots to maintain visual separation or to fly a visual approach, they can concentrate their efforts on separating the other IFR aircraft they are handling. The quicker an approach controller transfers the responsibility of separation to the pilot, the better service he or she can provide to the other aircraft that still require IFR control.

There are several factors a controller should consider before clearing a pilot to maintain visual separation or to fly a visual approach when wake-turbulence separation must be applied. First, winds have a significant effect on wake turbulence. A smaller aircraft upwind from a larger aircraft is unlikely to encounter any wake turbulence. However, it is not always practical or possible to have a smaller aircraft follow a larger aircraft on the upwind side. Traffic patterns, runway configurations, and expeditious handling sometimes do not make it practical to sequence aircraft based on crosswinds. Another consideration controllers need to make is the flightpath of the preceding aircraft compared to the flightpath of the following aircraft. Steep descents of larger aircraft for any reason could create a hazard for smaller following aircraft flying a normal descent to the same runway. This is because the smaller aircraft at some time could be below the glidepath of the larger aircraft.

Many more fast, small jet powered aircraft are being manufactured. It is no longer a "small aircraft fly slower than large aircraft" environment. Faster small jets following slower large jets could create a serious wake-turbulence problem since the smaller aircraft could get too close behind the larger jet. Intersecting runways also create a hazard when a small jet is cleared to land on a runway and its flightpath will take it through the flightpath of a larger jet that was landing or departing on a different runway.

The best prevention for avoiding wake turbulence is both pilot and controller awareness. Controllers must be aware of where wake turbulence could occur and how it will affect

other aircraft following. Crosswinds, steep descents, different airspeeds and crossing runways are factors controllers should consider. Pilots also have to be made aware of where the potential hazards exist. Sometimes giving a cautionary wake-turbulence advisory is not enough. The pilot needs to know if the aircraft he/she is following is on a steeper than normal descent, is flying slower, or if the preceding aircraft has departed or is landing on another runway. If the controllers are aware of potential wake-turbulence hazards, then they need to inform the pilots of those hazards and allow the pilot to adjust his/her flightpath accordingly.

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